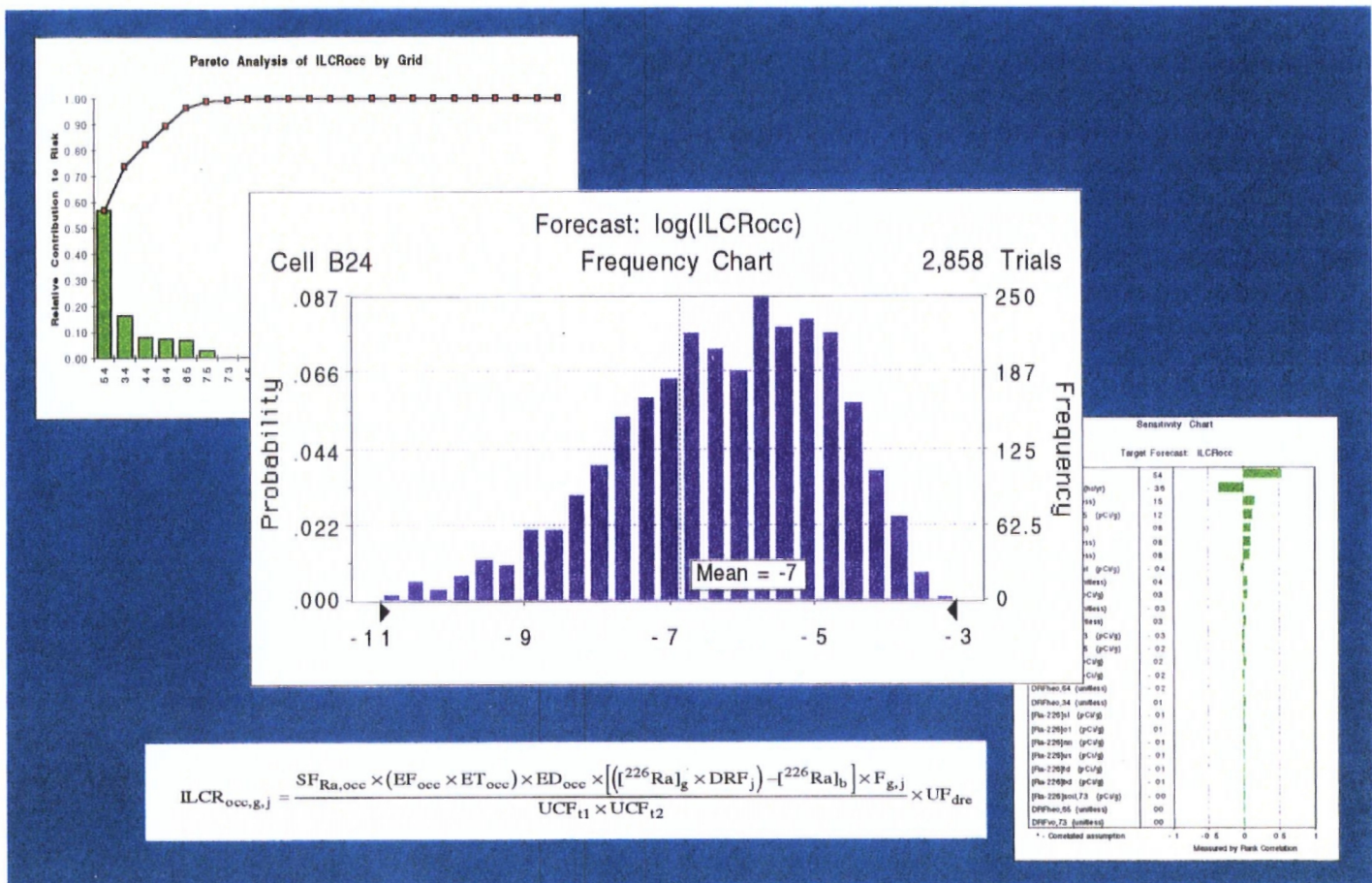


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Monsanto

**Stochastic Human Health
Baseline Risk Assessment**

**The Monsanto Company
Elemental Phosphorous Plant
Soda Springs, Idaho**

March 1996

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Stochastic Human Health Baseline Risk Assessment

The Monsanto Company Elemental Phosphorus Plant Soda Springs, Idaho

Prepared for:

**Monsanto Company
Soda Springs Plant
Soda Springs, Idaho**

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March 4, 1996



Executive Summary



MONTGOMERY WATSON

Executive Summary

This stochastic, or probabilistic, baseline risk assessment for the Monsanto Company's Soda Springs Plant builds upon the one conducted deterministically for Region 10 of the United States Environmental Protection Agency (EPA-10), by Science Applications International Corporation and Ecology & Environment, Inc. The deterministic risk models assign point estimates to represent each exposure and toxicity variable, and generate point estimates of risk. A stochastic risk model assigns probability distributions to represent each variable and yields a frequency distribution of risk estimates.

A stochastic model allows an evaluation of uncertainty—arising from either inherent natural variability in the model variables (*e.g.*, spatial heterogeneity in substance concentrations in the environment) or lack of knowledge about model variables (*e.g.*, the amount of soil an individual consumes) or model processes (*e.g.*, extrapolation of toxicological responses observed at high doses to predict effects at low-doses). It also allows correlations among the model variables to be considered (*e.g.*, younger, thus smaller, individuals generally consume more soil than older, thus larger, individuals).

Numerous conservative assumptions are typically incorporated into deterministic risk models, such as those used by EPA-10 to evaluate the Monsanto Plant. One drawback of this approach is that the conservatism compounds exponentially in proportion to the number of variables in the model. The mathematical consequence is that the deterministic point estimate of risk may overestimate realistic risks by orders of magnitude (Milloy, 1995). While no model is completely realistic, a stochastic risk model does provide a more accurate estimate of risk. Other advantages of a stochastic approach to risk estimation are:

- By generating a frequency distribution of estimates, stochastic modeling allows for direct quantification of precision and uncertainty;
- By allowing the assignment of a probability to each estimated risk value in the frequency distribution, stochastic modeling produces more representative estimates of risk that have statistical meaning;

- By using all of the information available on the risk model variables through use of probability distributions, the resulting frequency distribution of risk estimates is more complete;
- By allowing percentiles in the frequency distribution of risk estimates to be assigned, risk estimates can be compared, from scenario to scenario within a given site or between sites, in a meaningful manner.

This stochastic assessment was performed to conform with EPA policies requiring that uncertainty in risk estimates be quantified, that the likelihood of exposure scenarios be quantified, and that site remediation decisions not be based on overly conservative risk estimates. The deterministic risk assessment performed for EPA-10 provides valuable information regarding the dominant substances and exposure pathways for each of the exposure scenarios modeled. This screening information was used to focus the efforts of the stochastic assessment and those substance-pathway elements that would be most likely to pose a threat to human health or the environment.

Improving the understanding of the potential risks posed by the Monsanto Plant, by building upon the agency's assessment, provides managers at EPA-10, the State of Idaho's Division of Environmental Quality, and Monsanto, as well as plant workers and nearby residents, with an informed foundation upon which to manage such risks.

The results of the stochastic risk assessment are summarized below.

Human Health Risk Assessment Summary

Two human exposure scenarios are evaluated: an on-site occupational scenario and an off-site residential scenario. The occupational scenario evaluates individuals in the permanent, full-time work force at the plant, specifically those who work within the plant fence line. The residential scenario evaluates those individuals who live within the near vicinity of the plant (*i.e.*, those residing within about one mile of the plant fence line).

Baseline human health risk assessments are performed, under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), to determine the need, if any, for site remediation. With regard to exposures to systemic toxicants, a hazard

quotient, or HQ, in excess of 1.0 is generally regarded as unacceptable. With regard to exposures to carcinogenic substances, an incremental lifetime cancer incidence rate, or ILCR, in excess of 10^{-4} , or one in ten thousand, is generally regarded as unacceptable. (The background lifetime cancer incidence rate in North America is one in three.)

The results of each scenario are summarized below.

Occupational Scenario

As EPA-10's assessment indicates an absence of any hazards to workers—at present and in the future—that might be associated with exposures to systemic toxicants (*i.e.*, $HQ < 1.0$), the stochastic risk assessment does not include an analysis of such risks. With regard to exposure to carcinogenic substances, the results of the EPA-10 assessment indicate that external exposure to gamma radiation associated with radium-226 (^{226}Ra) is clearly the dominant constituent-pathway element in the risk model for the occupational scenario, given that this element accounts for at least 90% of the deterministic estimates. Thus, the stochastic model for occupational risks is appropriately focused on this constituent-pathway element.

The deterministic risk assessment conducted for EPA-10 estimates material-specific occupational ILCRs of about 10^{-4} for current occupational exposures. The stochastic assessment estimates an ILCR_{occ} distribution—for a person selected at random from the permanent, full-time work force—that has a 95th percentile, $\text{ILCR}_{\text{occ},0.95}$, of about 10^{-4} . Thus, despite different methods of analysis, the results of the deterministic and stochastic assessments are in agreement, within rounding error, for current occupational conditions.

Because Monsanto has approximately 100 years of proven ore reserves nearby, plans to continue operations at Soda Springs into the future, and has a track record of continual environmental improvement, current operational conditions at the plant provide a good, conservative approximation of future working conditions, and $\text{ILCR}_{\text{occ},0.95}$ is assumed to apply equally to both current and future subscenarios. EPA-10's assessment of future occupational risks assumes that an unshielded worker (*i.e.*, a worker who does not operate a vehicle or heavy equipment, the mass of which provides substantial gamma radiation shielding) is outdoors 8 hours every day while on the job. Such an assumption does not take into account the realities of the climate in Soda Springs and of actual working

conditions (*e.g.*, the 95th percentiles of job-specific outdoor-time distributions for unshielded workers correspond to 0.3 and 1.4 hours per day).

A worst-case stochastic evaluation of EPA-10's perspective on the future occupational subscenario was conducted to evaluate scenario uncertainty. Assuming that a future work force subpopulation works outdoors on the slag pile (within grid 34) and is unshielded, an $ILCR_{focc,34,EPA,0.95}$ of about 10^{-4} is estimated. The enhanced realism of the stochastic methodology thus confirms that the agency's deterministic estimates of future occupational risk are overly conservative; it also demonstrates that scenario uncertainty is relatively insignificant. If EPA-10 were to account for the climate and likely outdoor working conditions, the results of their deterministic version of the future occupational scenario would be significantly lower than the reported 10^{-3} .

Residential Scenario

EPA-10's assessment indicates that current residents are not at risk due to exposures to systemic toxicants (*i.e.*, $HQ < 1.0$). The stochastic assessment, therefore, does not include an analysis of such risks for current residents.

Under future conditions, EPA-10 estimates a hazard quotient, HQ, of 2, due to potential ingestion of fluoride (F) in ground water, to the south-southeast of Monsanto property, that past plant operations have affected. [The agency has estimated an HQ of 1.4 for selenium (Se) in the same area.] The likelihood of ground water in this area being used for drinking water is very low, given the proximity of the City of Soda Springs and the abundance of the city's water supply.

A more realistic assessment of risk associated with future ground-water consumption would incorporate a likelihood estimate for the future use of the affected ground water. A likelihood as unrealistically high as 50% would drop the HQ estimates to or below 1.0. However, based on the consideration of relevant and appropriate F and Se standards set under the Safe Drinking Water Act, it would be undesirable to have a ground-water well placed in the wrong location downgradient from their property. Given this obvious conclusion, a stochastic analysis of the risks to potential future residents related to ground-water consumption has not been conducted.

The results presented in the EPA-10 assessment for current residential exposures indicate that ingestion of soil containing elevated levels of arsenic accounts for about half of the cancer risk associated with the highest of three locations evaluated. Therefore, the current residential scenario evaluated in the stochastic assessment focuses on the effects associated with the ingestion of arsenic in soil. Of the three locations evaluated, only one, about 0.5 mile west of the plant, is currently inhabited. The EPA-10 assessment estimates a current residential ILCR of 0 (based solely on arsenic ingestion) for the inhabited location. The stochastic assessment estimates that a person selected at random from the current residential population within the near vicinity of the plant has an $ILCR_{\text{cres},0.95}$ of about 10^{-8} .

These results, which are in virtual agreement as to the insignificance or absence of risk to existing nearby residents, indicate that arsenic is obviously not the dominant problem at the single location that is currently inhabited. A closer inspection of EPA-10's assessment indicates that ingestion of soil with elevated levels of beryllium accounts for about 30% of the diffusely apportioned risk at this location. Thus, an alternative version of the current residential subscenario model, $ILCR_{\text{cres},\text{be}}$, was developed to better evaluate the inhabited area.

The estimate value of $ILCR_{\text{cres},\text{be},0.95}$ is also 10^{-8} , relative to EPA-10's deterministic estimate of 10^{-6} (based solely on beryllium ingestion). Although differing by two orders of magnitude, these results confirm that nearby residents are currently not subjected to any significant environmental health threats.

For the future residential scenario, EPA-10's assessment indicates that external radiation associated with ^{226}Ra accounts for at least 90% of the estimated potential risk. Therefore, the future residential scenario in the stochastic assessment focuses on the effects of gamma radiation associated with elevated levels of ^{226}Ra in soils. The agency's deterministic assessment estimates of future residential ILCRs range from 0 to 10^{-3} , whereas the stochastic assessment estimates that a randomly-selected person who lives in the near vicinity of the plant at some time in the future has an $ILCR_{\text{fres},0.95}$ of 10^{-7} . The difference between the two future residential assessments is due primarily to the difference in methodology.

The stochastic version of the future residential scenario assumes that land with residential development potential will be developed in a non-uniform manner which is dependent upon current land use and zoning. EPA-10 has suggested that it would be more appropriate to

assume uniform density of inhabitation of land with residential development potential. Thus, an alternative stochastic model was developed to evaluate this perspective. The resulting value of $ILCR_{fres,EPA,0.95}$ is 10^{-6} , an order of magnitude larger than Monsanto's perspective, but still well below the remedial action threshold of 10^{-4} .

An additional stochastic model was developed to conduct a worst-case evaluation of the future residential subscenario. This model focuses on a subpopulation of residents who might dwell on the north fence line of the plant (within grid 74). The resulting estimate of $ILCR_{fres,74,0.95}$ is also 10^{-6} , thus confirming, even at the worst location (and one of the least likely to be developed, given its proximity to the plant), that the risk to future inhabitants of the plant vicinity is far lower than estimated by EPA-10.

Summary Comparison of the Deterministic and Stochastic Human Health Baseline Risk Assessments

The information provided above is summarized in Table 1 to facilitate comparison between the stochastic and deterministic risk assessments. The results of both assessments agree on the lack of any current problem for plant workers and nearby residents. They also agree about the lack of a future problem with systemic toxicity to plant workers.

The stochastic assessment, in contrast to the deterministic assessment, demonstrates the absence of any future problem with respect to carcinogenicity for both plant workers and nearby residents. Specific questions that need attention to resolve these discrepancies between the two assessments are:

Future Occupational ILCR

- What is the likelihood of someone working outdoors all the time, year around, for 25 years at the plant at some point in the future?
- Which method of analysis—deterministic modeling or stochastic modeling—provides higher quality results in terms of precision quantification, accuracy, representativeness, comparability, and completeness?

Table 1. Summary Comparison of the Deterministic and Stochastic Human Health Baseline Risk Assessments for Monsanto's Soda Springs Plant. ^a

<u>Exposure Scenario</u>	<u>Deterministic Assessment</u>		<u>Stochastic Assessment</u>	
Occupational				
current	HQ	< 1.0	HQ _{occ,0.95}	< 1.0 ^b
	ILCR	10 ⁻⁴ ^c	ILCR _{occ,0.95}	10 ⁻⁴
future	HQ	< 1.0	HQ _{occ,0.95}	< 1.0 ^b
	ILCR	10 ⁻³ ^d	ILCR _{occ,0.95}	10 ⁻⁴
Residential				
current	HQ	< 1.0	HQ _{cres,0.95}	< 1.0 ^b
	ILCR	0	ILCR _{cres,0.95}	10 ⁻⁸
future	HQ	2	HQ _{fres,0.95}	< 1.0 ^d
	ILCR	0 to 10 ⁻³ ^e	ILCR _{fres,0.95}	10 ⁻⁷

^a A reasonable maximum estimate of HQ above 1.0, or a reasonable maximum estimate of ILCR above 10⁻⁴, is typically regarded as cause for site remediation. (A reasonable maximum estimate is one lying within the 90th to 98th percentiles.)

^b Because the deterministic assessment shows no problem, the stochastic assessment does not include an analysis of hazard associated with exposure to systemic toxicants.

^c One of six material-specific, subpopulation estimates does not exceed the 98th percentile of the stochastic estimate of ILCR_{occ}; five do, but do not exceed the 99.9th percentile.

^d Although a stochastic analysis was not performed, factoring the likelihood of future development of affected ground water would lower the HQ estimate to or below 1.0.

^e One of four estimates is zero, the three non-zero estimates exceed the 99.9th percentile of the stochastic estimate of ILCR_{fres}.

Future Residential HQ

- What is the likelihood of future development of the affected aquifer as a water supply?

Future Residential ILCR

- Which method of analysis—deterministic modeling or stochastic modeling—provides higher quality results in terms of precision quantification, accuracy, representativeness, comparability, and completeness?

The question of future aquifer development is moot from a remedial decision-making perspective because of the need to comply, regardless of risk, with relevant and appropriate standards of the Safe Drinking Water Act. With regard to the question of future worker behavior patterns, Monsanto believes that the assumptions used in the deterministic assessment are very conservative and thus amenable to refinement. With regard to the question of analysis quality, Monsanto believes that the proven methodology of the stochastic approach provides for a high-quality way to iteratively build upon and refine the results of the deterministic assessment.

Table of Contents



MONTGOMERY WATSON

TABLE OF CONTENTS

EXECUTIVE SUMMARY

1. PROBLEM FORMULATION

1.1 Summary of EPA-10 Baseline Risk Assessment	1
1.1.1 Occupational Scenario	1
1.1.2 Residential Scenario	2
1.2 Purpose of the Stochastic Baseline Risk Assessment	3
1.3 Scope of the Stochastic Baseline Risk Assessment	5
1.4 Report Organization	10

2. ANALYSIS

2.1 Toxicity Assessment	12
2.1.1 Cancer Potency Slope Factor for ²²⁶ Ra External Gamma Radiation Exposure	15
2.1.2 Cancer Potency Slope Factor for As Ingestion	16
2.1.3 Uncertainty Factor for Dose-Rate Effectiveness	17
2.1.4 Bioavailability Factor for As in Water	18
2.1.5 Toxicity Assessment Summary	20
2.2 Exposure Assessment	20
2.2.1 Occupational Scenario	23
2.2.2 Residential Scenario	37

3. RISK CHARACTERIZATION

3.1 Occupational Scenario	54
3.1.1 Risk Estimation	54
3.1.2 Risk Description	62
3.2 Residential Scenario	70
3.2.1 Current Residential Subscenario	70
3.2.2 Future Residential Subscenario	76

4. SUMMARY AND CONCLUSIONS

4.1 Occupational Scenario	86
4.1.1 Current Occupational Subscenario	86
4.1.2 Future Occupational Subscenario	88
4.2 Residential Scenario	89
4.2.1 Current Residential Subscenario	89
4.2.2 Future Residential Subscenario	89

LITERATURE CITED

TABLE OF CONTENTS

LIST OF TABLES

1.3-1	Constituents, Receptors, and Exposure Pathways Comprising the Risk Models for the Assessed Exposure Scenarios.....	7
1.3-2	Summary of Structural Modifications Incorporated into the Stochastic Risk Models for the Monsanto Soda Springs Plant	8
2.2.1.8-1	Composition of the Outdoor Area of the Monsanto Soda Springs Plant by Grid	32
2.2.2.2.6-1	Land-Use Evaluation for the Monsanto Plant and Vicinity.....	45
4-1	Summary and Comparison of Cancer Risk Estimates	87

LIST OF FIGURES

2.2-1	Extent of Elevated Arsenic, Radium, and Beryllium in Soil Near the Monsanto Soda Springs Plant.....	21
2.2-2	Receptor Grid Network for the Monsanto Soda Springs Plant	22
3.1.1.1-1	Plot of the Dependent Variable, $ILCR_{occ}$, in the Risk Model for the Occupational Scenario	56
3.1.1.2-1	Sensitivity Analysis of the Risk Model for the Occupational Scenario.....	58
3.1.1.2-2	Pareto Plot of the Location-Specific Contributions to $ILCR_{occ}$	60
3.1.1.2-3	Pareto Plot of the Job-Specific Contributions to $ILCR_{occ}$	61
3.2.1.1.1-1	Plot of the Dependent Variable, $ILCR_{res}$, in the Risk Model for the Current Residential Subscenario	72
3.2.1.1.2-1	Sensitivity Analysis of the Risk Model for the Current Residential Subscenario	74
3.2.2.1.1-1	Plot of the Dependent Variable, $ILCR_{fres}$, in the Risk Model for the Future Residential Subscenario	79
3.2.2.1.2-1	Sensitivity Analysis of the Risk Model for the Future Residential Subscenario	81
3.2.2.1.2-2	Pareto Plot of the Location-Specific Contributions to $ILCR_{fres}$	82

Chapter 1



MONTGOMERY WATSON

1 Problem Formulation

In January, 1995, Region 10 of the United States Environmental Protection Agency (EPA-10) published a baseline human health risk assessment, prepared by Science Applications International Corporation, for Monsanto Company's elemental phosphorus plant in Soda Springs, Idaho (SAIC, 1995). The EPA-10 assessment evaluated two human health exposure scenarios: an industrial scenario to assess potential health risks to the on-site work force; and, a residential scenario to assess potential health risks to off-site residents in the near vicinity of the plant. SAIC conducted an assessment of both the current and the potential future health risks for both scenarios.

The results of the EPA-10 assessment are summarized below in Subchapter 1.1, the purpose of the stochastic baseline risk assessment presented herein is stated in Subchapter 1.2, and the scope of this assessment is outlined in Subchapter 1.3. Subchapter 1.4 describes how this human health risk assessment report is organized.

1.1 Summary of EPA-10 Baseline Risk Assessment

This summary is presented in two parts. The occupational scenario at the plant is summarized in Section 1.1.1, and the residential scenario for the near vicinity of the plant is summarized in Section 1.1.2.

1.1.1 Occupational Scenario

For the industrial scenario, hereafter referred to as the occupational scenario, EPA-10 concludes that there is an absence of hazard associated with exposure to elevated levels of systemic toxicants (*i.e.*, non-carcinogens) found in the materials stockpiles, soil, and air within the plant fence line, under both current and potential future conditions.

Under current occupational exposure conditions to carcinogenic substances found elevated in the environment due to past and ongoing plant operations, reasonable maximum or conservative estimates of risk, in terms of the incremental likelihood of a worker's chance of developing cancer (an incremental lifetime cancer rate, or ILCR, over and above the background rate of cancer incidence), are reported to range from 7×10^{-5} to 5×10^{-4} . These

risk estimates apply to worker subpopulations, rather than to the entire population of plant workers, and they vary by material—baghouse dust, nodules, slag, road dust, treater dust, and underflow solids. In each case, the dominant pathway in terms of contribution to the overall risk estimate is external exposure to gamma radiation emitted from the short-lived decay nuclides of radium-226 (^{226}Ra). This pathway accounts for anywhere from about 90% of the total risk estimate associated with treater dust to almost 100% of that associated with the slag (see Tables 5-1a through 5-1f in SAIC, 1995; to ensure comparability, the risk estimates in these tables have been adjusted by subtracting background risk estimates provided in Table C-2).

Under potential future occupational exposure conditions to carcinogens, SAIC reports reasonable maximum risk estimates ranging from 1×10^{-3} to 2×10^{-3} . Under the conditions assumed for this subscenario, external exposure to radiation associated with ^{226}Ra also predominates, with the contributions from this pathway ranging from about 90%, for underflow solids, to almost 100%, for nodules and slag (see Tables 5-2a through 5-2f, adjusted for background estimates presented in Table C-2, in SAIC, 1995).

1.1.2 Residential Scenario

For the residential scenario, EPA-10 concludes that there is currently an absence of hazard associated with exposure to elevated levels of systemic toxicants in the soil, air, and water in the near vicinity of the plant. They conclude that, in the future, it is possible that there could be a hazard associated with drinking ground water downgradient, to the south-southeast, of the plant. The ground water at this location contains elevated levels of fluoride (F) and selenium (Se) (see Table 5.5a in SAIC, 1995).

Under current exposure conditions to carcinogens found or predicted to be elevated in soil and air, reasonable maximum ILCR estimates are reported to range from 6×10^{-6} to 2×10^{-5} for hypothetical individuals residing to the north, west, and south of the plant (see Tables 5-4a through 5-4c in SAIC, 1995, and adjust estimates for background values presented in Table C-3). No single constituent-pathway element dominates the current residential risk estimates. However, ingestion of beryllium (Be) in soil accounts for much of the risk at two of the locations—about 40% to the north and about 30% to the west. Ingestion of arsenic (As) accounts for about 50% of the highest of the three risk estimates, the one for the southern location.

Under potential future residential exposure conditions to carcinogens, EPA-10 reports reasonable maximum ILCR estimates ranging from 3×10^{-6} to 2×10^{-3} for individuals who would happen to reside at one of four locations to the south or north of the plant (see Tables 5-5a through 5-5d in SAIC, 1995, adjusting for background values in Table C-3). Ingestion of Be in soil accounts for about 30% of the smallest of the four estimates, whereas external radiation associated with ^{226}Ra accounts for about 90% to almost 100% of the risk estimates in the remaining three locations.

1.2 Purpose of the Stochastic Baseline Risk Assessment

This risk assessment for Monsanto Company's elemental phosphorus plant has a three-fold purpose:

- To build upon the deterministic risk assessment by accounting for uncertainties in the risk model variables and in the relationships between the variables;
- To quantify the uncertainty in the health risk estimates; and,
- To comply with the provisions of the agency's final exposure assessment guidelines (EPA, 1992), and with the agency's recent Superfund reforms (EPA, 1995a).

The risk assessment presented herein is performed stochastically, *i.e.*, probabilistically, and builds upon the deterministic assessment performed by SAIC (1995). A deterministic model is one where all input variables are represented as point estimates and the resulting output—in this case a risk estimate—also takes the form of a point estimate.

In a stochastic model, input variables are represented by probability distributions to account for uncertainty attributable to either inherent natural variability (*e.g.*, environmental spatial heterogeneity or variation in human behavior) or lack of knowledge (*e.g.*, use of sample statistics to represent population statistics or use of toxicity data obtained from high-dose responses to predict low-dose responses). Using the same model structure as is used in a deterministic model, a computer randomly selects, in proportion to their relative probabilities, values from each input variable and calculates a trial result. Repeated trials of

this nature constitute a process called Monte Carlo simulation; after many such trials, a frequency distribution of results is generated. Therefore, the output of a stochastic model takes the form of a probability distribution.

If there is any uncertainty to the relationship between output and input variables, the output can not be completely explained by the deterministic approach and such an approach provides a poor prediction. Health risk models are inherently uncertain due to the uncertainties associated with the environmental, biological, and behavioral variables of which the models are composed. Because of these uncertainties, a stochastic model provides a higher quality risk estimate.

A stochastic risk model fully incorporates the relationships and results established by a corresponding deterministic model, but goes beyond that to explain or estimate risk based on other factors, as well. The stochastic approach is the preferred method when data for each of the input variables are highly uncertain or when the amount of data is simply insufficient to establish a precise or exact (*i.e.*, deterministic) relationship between the output (*i.e.*, the risk estimate) and input variables. A stochastic model can be viewed as having, in addition to a deterministic component, a random error component that explains the existing uncertainties. The probability distributions used in a stochastic model not only incorporate all the available information, but also explain the uncertainty in that information.

In addition to enhancing quality in model outputs, stochastic risk modeling has the inherent advantage of providing risk managers with quantified levels of uncertainties in the results. Uncertainty quantification not only provides risk managers with a rational means by which to make a protective remediation decision, it also provides a basis upon which decisions can be made as to what, if any, additional site characterization is needed to refine the risk model to ensure optimal decision making.

The administrative order on consent—pursuant to the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA, 42 USC §9601 *et seq.*)—for the Monsanto Soda Springs Plant (EPA-10 and Monsanto, 1991) requires that all work "be conducted in accordance with the requirements of CERCLA, the NCP [National Oil and Hazardous Substances Pollution Contingency Plan, 40 CFR §300, the implementing regulations for CERCLA], and all applicable EPA guidance ... as may be amended or modified by EPA."

In May, 1992, EPA published final exposure assessment guidelines in the *Federal Register*, for use by "exposure and risk assessors in the Agency and those exposure and risk assessment consultants, contractors, or other persons who perform work under Agency contract or sponsorship" (EPA, 1992). These guidelines require that risk assessment uncertainties be quantified, that bounding or overly conservative estimates of risk not be used as the basis for requiring site remediation, and that the likelihood of the occurrence of an exposure scenario be stated.

In October, 1995, EPA published a set of administrative reforms for Superfund. Several of the reforms are pertinent to the risk assessment process. Such reforms include ensuring that all risk assessments are clear, transparent, consistent, reasonable, and grounded in reality, and prioritizing actions on the basis of risk.

The use of stochastic modeling allows for conformance with the above-mentioned guidance—and, thus, with the administrative order on consent—in that uncertainties in the results are quantified, and information is generated with which to evaluate the validity of the point estimates of risk provided in SAIC (1995). Explicit acknowledgment and documentation of uncertainties in the risk models achieves the reform goals of clarity and transparency. Explicit evaluation of uncertainties through stochastic analysis achieves the reform goals of consistency, reasonableness, and reality enhancement.

1.3 Scope of the Stochastic Baseline Risk Assessment

The assessment presented in this report builds upon the work already performed by EPA-10. The results presented in SAIC (1995) indicate that external exposure to gamma radiation associated with ^{226}Ra is clearly the dominant constituent-pathway element in the risk model for the occupational scenario, accounting for at least 90% of the deterministic risk estimate. Accordingly, the stochastic model for the occupational scenario focuses entirely on this constituent-pathway element. The remaining 10% or less of the risk not evaluated stochastically can be ignored given that its magnitude is trivial relative to that attributable to external gamma-radiation exposures associated with ^{226}Ra .

Current and future occupational subscenarios are presented in EPA-10's assessment (SAIC, 1995). Monsanto has approximately 100 years of proven ore reserves nearby and plans to continue operations at Soda Springs into the foreseeable future. Monsanto thus

assumes that future operations at the plant are well approximated by current conditions. Therefore, there is no basis to distinguish between current and future conditions, and no such distinction is made in the occupational scenario modeled herein. A worst-case stochastic evaluation of EPA-10's perspective on the future occupational subscenario is, however, presented to allow for an evaluation of scenario uncertainty.

The results of EPA-10's deterministic risk assessment indicate that ingestion of soil containing elevated levels of As accounts for much (about 50%) of the risk associated with the highest of three locations evaluated. Thus, the current residential subscenario modeled in this assessment focuses on the effects associated with the ingestion of As in soil. Ingestion of Be in soil, however, accounts for much (about 30%) of the risk at the only location within the plant vicinity—to the west—where people currently live. Thus, results of a Be-ingestion version of the current residential subscenario are also presented.

For the future residential subscenario, EPA-10's assessment indicates that external radiation associated with ^{226}Ra accounts for at least 90% of the risk estimates for three of the four locations evaluated, including areas to the south, in the direction of Soda Springs, where most of the future residential development can be anticipated. The future residential subscenario presented herein thus focuses on evaluating the effects of gamma radiation emanating from elevated levels of ^{226}Ra in soils. Two supplemental analyses for the future residential subscenario are provided—EPA-10's perspective on the subscenario to evaluate scenario uncertainty, and a worst-case subpopulation evaluation.

Table 1.3-1 summarizes the primary scope of this assessment according to the elements of the site conceptual model [B. Wright, D. Crawford, and R. Lee, Golder Associates Inc. (GAI) (Memorandum to Monsanto Soda Springs Plant Remedial Investigation/Feasibility Study Project File) May 20, 1994].

The modeling for this assessment was conducted on Excel[®] spreadsheets (Microsoft Corporation, 1992) with the Monte Carlo simulation add-on, Crystal Ball[®] (Decisioneering, Inc., 1994). The stochastic analyses are based on models that are structurally virtually identical to those used in the corresponding deterministic analyses (SAIC, 1995). The exceptions—minor modifications to account for variable and process uncertainties, spatial heterogeneity in the concentrations of elevated constituents in the environment, and spatial heterogeneity in the receptor populations—are listed in Table 1.3-2 by scenario. Comparisons of the basic model structures used herein vs. those

Table 1.3-1. Constituents, Receptors, and Exposure Pathways Comprising the Risk Models for the Assessed Exposure Scenarios.

Occupational Scenario

- Constituent of interest— ^{226}Ra in on-site materials and soils;
- Receptor of interest—a randomly-selected, permanent, full-time employee at the plant; and,
- Exposure pathway of interest—external gamma radiation.

Current Residential Subscenario

- Constituent of interest—As in soils;
- Receptor of interest—a randomly-selected individual who resides in the near vicinity (within roughly one mile) of the plant; and,
- Exposure pathway of interest—soil ingestion.

Future Residential Subscenario

- Constituent of interest— ^{226}Ra in soils;
- Receptor of interest—a randomly selected individual who, at some point in the future, resides in the near vicinity (within roughly one mile) of the plant; and,
- Exposure pathway of interest—external gamma radiation.

Table 1.3-2. Summary of Structural Modifications Incorporated into the Stochastic Risk Models for the Monsanto Soda Springs Plant.

Occupational Scenario (see Appendix A)

- The concentration variable has been modified to account for spatial heterogeneity on a grid-specific basis as opposed to a material-specific basis.
- An uncertainty factor was added to account for process uncertainty associated with straight-line extrapolations of high-dose and continuous-dose carcinogenic effects to low-dose, fractionated-dose exposures.
- Weighting factors were assigned to each grid, on the basis of the location of personnel and type of job performed, to account for spatial heterogeneity among the work force and to allow estimation of a risk for a worker selected at random.

Residential Scenario (see Appendix I)

As ingestion model

- Bioavailability factors were added to adjust dose and toxicity to an absorbed-dose basis.
- A fraction was added to account for the fact that not all dirt (*i.e.*, soil plus dust) consumed is derived from soil.
- A fraction was added to account for the fact that not all dirt consumed is consumed at the residence.
- Weighting factors were assigned to each grid, on the basis of the location of residential units, to account for spatial heterogeneity among the residential population and to allow estimation of a risk for a resident selected at random.

Table 1.3-2. Summary of Structural Modifications Incorporated into the Stochastic Risk Models for the Monsanto Soda Springs Plant, continued.

Residential Scenario, continued

²²⁶Ra external gamma exposure model

- A fraction was added to account for time spent outdoors where exposure can occur.
- A fraction was added to account for the fact that not all outdoor time is spent at the residence.
- An uncertainty factor was added to account for process uncertainty associated with straight-line extrapolations of high-dose and continuous-dose carcinogenic effects to low-dose, fractionated-dose exposures.
- Weighting factors were assigned to each grid, on the basis of the likely location of future residential units given patterns of zoning and land use, to account for spatial heterogeneity among the residential population and to allow estimation of a risk for a future resident selected at random.

used in SAIC (1995) are presented in Appendix A for the occupational scenario, and, for the residential scenario, in Appendix J.

1.4 Report Organization

Chapter 2 of this human health risk assessment report, "Analysis," provides a more detailed discussion of the model structures and defines the assumptions in each model used to define each of the independent variables, both stochastically herein and deterministically in SAIC (1995). Chapter 3, "Risk Characterization," provides the results and interpretation of the risk estimation process for each human exposure scenario. Twenty-one appendices are included to provide documentation of model structures, inputs, and outputs.

Chapter 2



MONTGOMERY WATSON

2 Analysis

The analysis phase of a risk assessment consists of two steps—toxicity assessment and exposure assessment. Subchapter 2.1 documents the toxicity assessment; Subchapter 2.2 documents the exposure assessment.

The following formula summarizes the risk model:

$$ILCR = T \times D$$

Equation 2-1

where:

- ILCR is the incremental lifetime cancer incidence rate (unitless) for exposure to elevated concentrations of ^{226}Ra or As, as appropriate;
- T is the toxicity component of the model {grams per picocurie-year [g/(pCi·yr)] for ^{226}Ra , kilogram-days per milligram (kg·d/mg) for As} for exposure to ^{226}Ra or As, as appropriate; and,
- D is the dose [pCi·yr/g for ^{226}Ra , mg/(kg·d) for As] resulting from the relevant exposure [a conversion to a radiation dose (*e.g.*, millirems per year) is not necessary for ^{226}Ra given the units in which T are expressed].

For each scenario, Subchapter 2.1 addresses the component elements of T and Subchapter 2.2 addresses the component elements of D. The Crystal Ball® reports presented, for the occupational scenario, in Appendix F and, for the residential scenario, in Appendices L and Q define all input variables in the models. (Supplemental modeling reports are provided in Appendix I—a worst-case evaluation of EPA-10's perspective on the future occupational subscenario, Appendix N—a Be-ingestion version of the current residential subscenario, Appendix S—an evaluation of EPA-10's perspective on the future residential subscenario, and Appendix U—a worst-case evaluation of the future residential subscenario.)

2.1 Toxicity Assessment

This portion of the analysis mathematically defines the toxicity and process-uncertainty variables in the risk models. A qualitative discussion of the toxicology of external gamma radiation and arsenic ingestion is provided below, and is followed by a quantitative evaluation of the toxicity-related model variables.

The estimation of radiation risks is based largely on cancer data from the survivors of the atomic bomb. More than half of this population is alive and prospective epidemiology studies are in progress. Many scientific organizations, both national (*e.g.*, National Council on Radiation Protection and Measurements, NCRP, and the National Research Council's Committee on the Biological Effects of Ionizing Radiation, BEIR) and international (*e.g.*, International Commission on Radiological Protection, ICRP, and the United Nations Scientific Committee on Effects of Atomic Radiation, UNSCEAR), have reviewed the extensive epidemiological data on this population, and for populations exposed to radiation through medical treatment or occupational activities, to develop cancer risk estimates. The EPA has used these evaluations to develop radionuclide-specific cancer potency slope factors.

The extrapolations made in the evaluations raise obvious concerns about how relevant data from highly-exposed populations, often with their own distinct background cancer incidence rates, are to populations exposed to protracted and low doses of radiation. The *BEIR V* report (National Research Council BEIR, 1990) recognizes that, at low doses of gamma radiation, the response may not be linear and that the range of uncertainty in the risk estimates extends to zero. Specific toxicological uncertainties are:

- Reconstruction of the actual doses, *i.e.*, dosimetry, of the exposed individuals introduces both random and systematic errors.
- Diagnostic inaccuracies affect the quality of the epidemiological database itself.
- The choice of a risk-projection model introduces uncertainty. For example, because 60% of atomic bomb survivors are still alive, it is necessary to project future cancer incidences. Two types of risk-projection models—the constant additive, or multiplicative, model and

the constant absolute, or additive, model—provide different estimates of projected cancer rates.

- Cultural extrapolations introduce uncertainties, as different cultures often have different background cancer rates.
- The extrapolation of risk estimates based on data associated with high-dose and high-dose rate exposures to derive estimates of effects at fractionated low-dose exposures is perhaps the most important of the uncertainties introduced. The *BEIR V* committee suggests that a dose-rate effectiveness (*i.e.*, reduction) factor of between 2 and 10, with a single best estimate of 4, is appropriate for the estimation of the incidence of solid cancers. For estimation of the incidence of leukemia, the same range of dose-rate effectiveness factors has been suggested (NCRP, 1993), and the *BEIR V* committee reports a single best estimate of 2.1. The current consensus recommendation is to conservatively apply a factor of 2 to deterministic evaluations of the effects of low-dose and low-dose-rate gamma radiation exposures.

The EPA's oral cancer potency slope factor for inorganic As is currently based upon epidemiological studies of a Taiwanese population (Tseng *et al.*, 1968; Tseng, 1977). While these studies suggest an association of skin tumors and consumption of water with elevated levels of As, they suffer from the following methodological problems that introduce significant uncertainties in the toxicity evaluation:

- The studies were not designed to estimate individual doses, and the exposures were estimated. Approximately 40,000 individuals were assigned to three exposure groups on the basis of average As concentrations in village well waters. There was a wide range of As concentrations between individual wells, and it was not possible to determine the well water concentrations to which individuals with specific tumors were exposed. In estimating exposures of the Taiwanese population to derive the cancer potency slope factor, EPA used the standard point-estimate drinking water consumption of 2 liters per day (L/d) for a 70-kg person. However, in the derivation of the chronic reference dose for As, which was based on the same studies,

EPA used the more appropriate assumptions for the rural Taiwanese population of 4.5 L/d water consumption and 55 kg body weight. In addition, there are data indicating that EPA underestimated the contribution of inorganic As in the food supply in Taiwan (Schoof *et al.*, 1994). These assumptions obviously have a strong influence on the dose-response curve used to estimate the cancer potency slope factor.

- The background cancer rates and the dietary habits of the Taiwanese population are significantly different from the United States population. In fact, the poor nutritional status of the rural Taiwanese population, marked by a low protein intake, may have a significant effect on the toxicity of inorganic As. Methylation of As is one of the major mechanisms of detoxification, and it has been shown, in animal studies, that low protein diets result in decreased excretion of methylated forms of As and increased As retention. Thus, direct extrapolation from one culture to the other introduces additional uncertainty.
- The results of the Taiwanese studies are inconsistent with the results of epidemiological studies in the United States, where no association between As ingestion and skin tumor incidence has been demonstrated.
- Evidence exists that As causes cancer via a threshold mechanism (Marcus and Rispin, 1988). The biochemical mechanism for the threshold is methylation. Thus, the use of a linear model for estimating the cancer potency slope factor is probably not appropriate.

The toxicity component of the ^{226}Ra risk models for the occupational and future residential scenarios is:

$$T_{\text{Ra}} = SF_{\text{Ra}} \times UF_{\text{dre}}$$

Equation 2.1-1

where:

- T_{Ra} is the toxicity factor for external exposure to gamma radiation from ^{226}Ra [g/(pCi·yr)];

- SF_{Ra} is the cancer potency slope factor for ^{226}Ra external gamma radiation exposure [g/(pCi·yr)]; and,
- UF_{dre} is the uncertainty factor for dose-rate effectiveness (unitless), which accounts for uncertainties associated with straight-line extrapolation of radiological cancer potency at high doses or continuous doses to that, if any, at low-dose or fractionated-dose exposures.

For the current residential subscenario, the As ingestion toxicity submodel is:

$$T_{As} = \frac{SF_{As}}{BF_{w,As}}$$

Equation 2.1-2

where:

- T_{As} is the toxicity factor for ingestion of As (kg·d/mg);
- SF_{As} is the cancer potency slope factor for As ingestion (kg·d/mg); and,
- $BF_{w,As}$ is the bioavailability factor (unitless) for the ingestion of As in water (*i.e.*, the fraction of As absorbed when consumed in water).

The following sections define the four variables.

2.1.1 Cancer Potency Slope Factor for ^{226}Ra External Gamma Radiation Exposure

The EPA (1995b) endorses the use of a cancer potency slope factor, SF_{EPA} , for various carcinogens. For the external exposure to ^{226}Ra -derived gamma radiation, this value, $SF_{Ra,EPA}$, is 6.74×10^{-6} g/(pCi·yr) [this value is 12% higher than the value used in SAIC (1995)]. The value derives from a median estimate of unit risk formerly endorsed by international and national radiation protection organizations for use on the general population. These organizations suggest the use of an even lower value—23% lower than the unit risk upon which the $SF_{Ra,EPA}$ is based—when evaluating occupational

populations (ICRP, 1991; NCRP, 1993). The median estimate of the occupational slope factor, $SF_{Ra,occ}$, thus becomes:

$$SF_{Ra,occ} = 6.74 \times 10^{-6} \frac{g}{pCi \cdot yr} \times (1 - 0.23) = 5.2 \times 10^{-6} \frac{g}{pCi \cdot yr}.$$

Equation 2.1.1-1

As EPA is currently reluctant to represent SFs as variable parameters in risk models [EPA Region 3 (EPA-3), 1994; EPA Region 8 (EPA-8), 1995], $SF_{Ra,occ}$ is represented by a point estimate of $0.0000052 \text{ g/(pCi} \cdot \text{yr)}$. For the residential scenario, the appropriate slope factor, $SF_{Ra,res}$, must apply to the general population. Therefore, the occupational adjustment is omitted, and $SF_{Ra,res}$ is represented by a point estimate of $0.00000674 \text{ g/(pCi} \cdot \text{yr)}$. These values incorporate the *BEIR V*-recommended dose-rate effectiveness factor of 2. On average, these values very likely overestimate the carcinogenic potency of ^{226}Ra for reasons specified in the qualitative discussion at the beginning of this subchapter. Ignoring uncertainty in the slope factor, however, will result in some degree of uncertainty underestimation in the risk estimate (*i.e.*, low risk estimates will be somewhat overestimated, and high risk estimates will be somewhat underestimated).

The above SF_{Ra} s account for the external gamma radiation effects of the short-lived radionuclides in the ^{226}Ra decay chain: radon-222, polonium-218, lead-214, bismuth-214, and polonium-214. These decay-chain products have very short half-lives, ranging from four days to one minute, and are thus assumed to be in equilibrium with ^{226}Ra . As ^{226}Ra is principally an alpha-particle-emitting radionuclide, the gamma radiation is actually attributable to its decay-chain products.

2.1.2 Cancer Potency Slope Factor for As Ingestion

For the ingestion of inorganic As, EPA (1993) endorses the use of a unit risk factor, a maximum-likelihood estimate, which converts, upon the application of standard agency exposure assumptions, to a $SF_{As,EPA}$ of $1.75 \text{ kg} \cdot \text{d/mg}$. This value is adopted as SF_{As} .

This value, on average, very likely overestimates the carcinogenic potency of ingested inorganic As, for reasons specified in the qualitative discussion at the beginning of this subchapter. However, as mentioned in Section 2.1.1, ignoring uncertainty in SF_{As} will result in some degree of underestimation of uncertainty in the risk estimate for the current residential scenario.

2.1.3 Uncertainty Factor for Dose-Rate Effectiveness

A unitless factor to account for the uncertainty in extrapolating the rate of cancer incidence attributable to high-dose, high-dose-rate exposures to predict cancer rates resulting from low-dose, fractionated exposures, UF_{dre} , has been added to the ^{226}Ra toxicity submodel. As mentioned in Section 2.1.1 above, EPA is reluctant to acknowledge and incorporate uncertainties in slope factors. EPA does, in a conservative manner, account for dose-rate effectiveness in the development of their radiological slope factors. However, the residual uncertainty unaccounted for is important. This factor is thus presented here as a variable in the toxicity submodel, but it is equally as valid to regard UF_{dre} as an exposure factor—one that characterizes the quality of the radiation in question.

The EPA's slope factors for radiological substances are extrapolated from data obtained from high-dose, short-duration atomic detonation and medical treatment events. Such circumstances are far different from low-dose (within that range of national background levels for gamma radiation), long-duration exposures that are of interest at the Monsanto plant. The UF_{dre} , or an analogous extrapolation uncertainty factor, is not used in the As toxicity submodel because the ingestion of As in water is known to cause skin cancer at naturally occurring concentrations, albeit at the very high range of such concentrations. Thus, the degree of extrapolation in the As toxicity submodel is not nearly as great as it is in the ^{226}Ra submodel. (Although an extrapolation uncertainty factor is not used in the As toxicity submodel, it would be more technically correct to include one.)

Uncertainty associated with high-dose-to-low-dose extrapolation is a form of process uncertainty, as opposed to variable uncertainty (*e.g.*, the type of uncertainty associated with the bioavailability factor discussed in Section 2.1.4). The variable UF_{dre} , however, can be developed to account for the extrapolation uncertainty, and maximum-entropy inference, applied to the fundamental knowledge of general dose-response relationships, provides a means by which to construct an uncertain distribution to represent the variable.

The *BEIR V* report indicates that dose-rate effectiveness factors of between 2 and 10 are repeatedly observed in animal studies. The radiological slope factors endorsed by EPA incorporate a factor of 2 (*i.e.*, the high-dose, short-duration slope factor has been multiplied by 0.50 for use in estimating risks at protracted, low-dose exposures). As this adjustment has already been made, a residual uncertainty of between 1 and 5 remains. As UF_{dre} is a multiplicative variable in the Equation 2.1-1, the residual uncertainty bounds are

inverted and become 0.20 and 1.00. With this set of knowledge constraints pertaining to the UF_{dre} distribution, one can apply maximum-entropy inference (Jaynes, 1957; Buckley, 1985; Goodman, 1987; Harr, 1987; Kaplan, 1987; Montgomery Watson and Envirochem, 1995; Lee and Wright, 1994) to obtain a broad approximation of the distribution.

Maximum-entropy inference provides the most uncertain (*i.e.*, broadest) distribution possible given the available knowledge constraints. The term "state-of-knowledge distribution" accurately describes a probability distribution derived by maximum-entropy inference. The advantage of using a distribution developed under this method is that it is mathematically the most uncertain distribution possible given the set of knowledge constraints imposed. The risk assessor's uncertainties are thus openly admitted and quantified with this technique, and the use of uncertain model inputs gives rise to an uncertain or broad model output.

The knowledge constraints for UF_{dre} consist of estimates of the lower and upper bounds, and these constraints lead to a uniform distribution as the one that is most uncertain, and this distribution is denoted as $U(0.20, 1.00)$. This variable accounts for the fact that national and international consensus documents agree that the dose-response for radiologically-induced cancer is likely to be somewhat sublinear at low doses and low dose rates. The implied value of UF_{dre} used in SAIC (1995), 1.00, is at the 100th percentile of $U(0.20, 1.00)$.

2.1.4 Bioavailability Factor for As in Water

Not all ingested As is bioavailable (*i.e.*, absorbed into the bloodstream). Therefore, the amount ingested in soil must be reduced to account for absorption, and, correspondingly, the slope factor must be increased to account for the degree of absorption associated with the studies upon which the cancer potency is based upon. Because the epidemiological study upon which SF_{As} is based is a water-ingestion study, this means that SF_{As} must be increased through dividing the bioavailability factor for As in water, $BF_{w,As}$. This adjustment, in conjunction with lowering the dose by multiplying by the bioavailability factor for As in soil, allows the risk to be estimated on an absorbed-dose basis.

The Agency for Toxic Substances Disease Registry reports that inorganic As is 75% bioavailable when ingested in water (Agency for Toxic Substances Disease Registry, 1991). If the mean of the bioavailability factor, μ_{BF} , is estimated at 0.75, and, on the basis

of physical constraint, the lower and upper bounds of the distribution— λ_{BF} and v_{BF} , respectively—are set at 0 and 1.00, maximum-entropy inference can be used to generate a beta distribution after calculating a standard deviation, σ_{BF} , that yields the most uncertain distribution. Such a standard deviation is calculated as follows (Lee and Wright, 1994):

$$\sigma = \mu \times \left\{ 1 - \left[0.41 \times \left(\frac{\mu - \lambda}{v - \lambda} \right) \right] - \left[1.16 \times \left(\frac{\mu - \lambda}{v - \lambda} \right)^2 \right] + \left[0.57 \times \left(\frac{\mu - \lambda}{v - \lambda} \right)^3 \right] \right\}$$

Equation 2.1.4-1

A beta distribution is defined as $\beta(\alpha, \beta, \lambda, v)$, where α and β are shape factors, and λ and v are the lower and upper bounds. The following expressions define the two shape factors:

$$\alpha = \frac{(\mu - \lambda) \times \left[\frac{(\mu - \lambda) \times (v - \mu)}{\sigma^2} - 1 \right]}{v - \lambda}$$

Equation 2.1.4-2

$$\beta = \frac{(\mu - \lambda) \times (v - \mu)}{\sigma^2} - 1 - \alpha$$

Equation 2.1.4-3

The above equations yield the beta distribution, $\beta(2.4, 0.81, 0, 1.00)$, for $BF_{w,As}$. The implied value used in SAIC (1995), 1.00, is at the 100th percentile of this distribution.

While $BF_{w,As}$ is clearly a toxicity factor, it is necessary to incorporate it stochastically so that the As-ingestion modeling is conducted on an absorbed-dose basis. Not doing so would result in the overestimation of low-end risks and, more importantly, the underestimation of the high-end risks that are of interest to risk managers. In effect, $BF_{w,As}$ serves to increase the effective carcinogenic potency of As.

2.1.5 Toxicity Assessment Summary

The results of the toxicity assessment are summarized as follows:

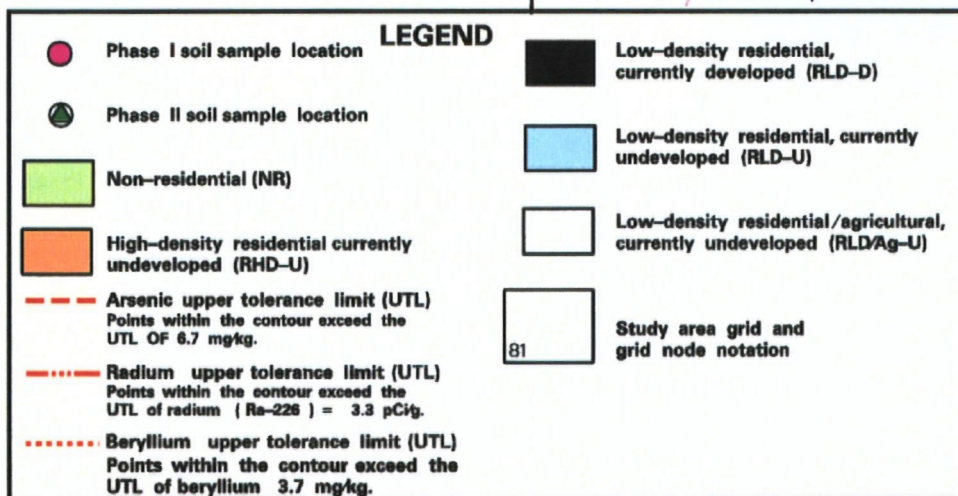
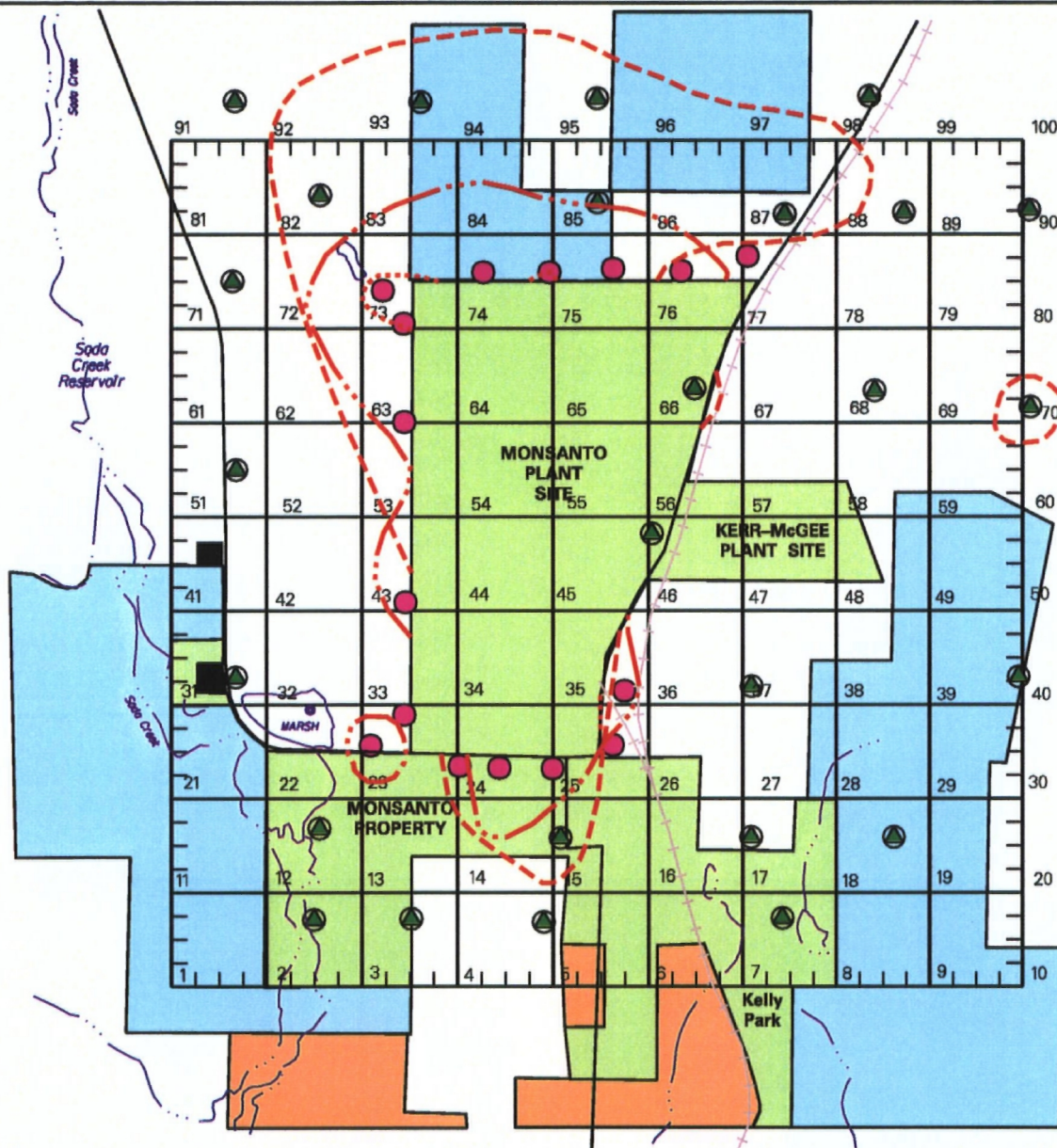
<u>Variable</u>	<u>Deterministic Definition</u>	<u>Stochastic Definition</u>
SF _{Ra,occ}	4.6×10^{-6} g/(pCi·yr)	not defined
SF _{Ra,res}	6.0×10^{-6} g/(pCi·yr)	not defined
SF _{As}	1.75 kg·d/mg	not defined
UF _{dre}	1.00	U(0.20, 1.00)
BF _{w,As}	1.00	$\beta(2.4, 0.81, 0, 1.00)$

No significant correlation is expected to exist between these five variables (with the exception of SF_{Ra,occ} and SF_{Ra,res}, which could be expected to be highly correlated; however, these two variables appear in different models and, in addition, are treated as non-variable parameters). Therefore, no correlation between them is assigned in the model.

2.2 Exposure Assessment

This portion of the analysis mathematically defines the variables and parameters in the exposure component of the risk model. It is presented in two sections: Section 2.2.1 addresses the occupational scenario, and Section 2.2.2 addresses the two residential subscenarios.

To account for environmental and behavioral spatial heterogeneity in the environment and in the behavior of receptors on and near the plant, 100 nodes were established to form an 81-grid network over the plant and its near vicinity. This grid network, shown in Figure 2.2-1, allows for enhanced spatial analysis in this exposure assessment. The extent of off-site soil affected by past and ongoing plant operations is displayed for As and ²²⁶Ra (Be is also plotted as a reference for the supplemental evaluation of the current residential subscenario.) Figure 2.2-2 shows those grids which encompass portions of the plant; these are the grids used in the occupational exposure assessment.

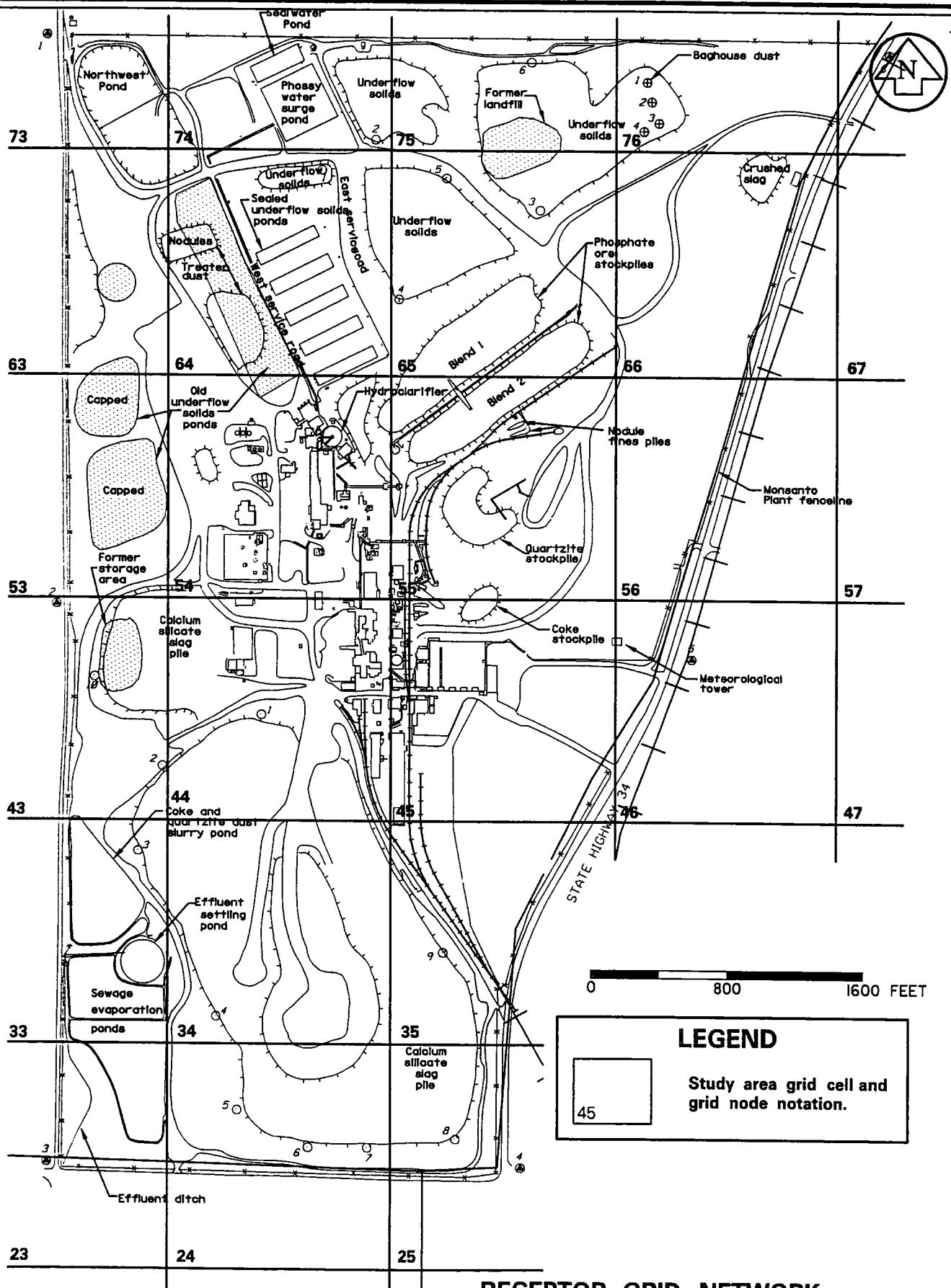


0 2000 4000 FEET



MONTGOMERY WATSON

**EXTENT OF ELEVATED ARSENIC, RADIUM,
AND BERYLLIUM IN SOIL NEAR THE
MONSANTO SODA SPRINGS PLANT
FIGURE 2.2-1**



RECEPTOR GRID NETWORK
FOR THE MONSANTO
SODA SPRINGS PLANT
FIGURE 2.2-2

2.2.1 Occupational Scenario

To account for spatial heterogeneity in ^{226}Ra concentrations, the distribution of employees, and distribution of types of job assignments across the plant, the exposure assessment for the occupational scenario is performed on a location- and job-specific basis:

$$D_{\text{occ,g,j}} = \frac{(EF_{\text{occ}} \times ET_{\text{occ}}) \times ED_{\text{occ}} \times \left[([^{226}\text{Ra}]_{\text{g}} \times \text{DRF}_{\text{j}}) - [^{226}\text{Ra}]_{\text{b}} \right] \times F_{\text{g,j}}}{\text{UCF}_{\text{t1}} \times \text{UCF}_{\text{t2}}} \quad \text{Equation 2.2.1-1}$$

where:

- $D_{\text{occ,g,j}}$ is the occupational grid- and job-specific dose [$\text{pCi}\cdot\text{yr}/(\text{kg}\cdot\text{g})$];
- $EF_{\text{occ}} \times ET_{\text{occ}}$ is the product (hours per year, hr/yr) of occupational exposure frequency (*i.e.*, the days of exposure per year) and exposure time (*i.e.*, the hours of exposure per day);
- ED_{occ} is the occupational exposure duration, or employment duration, at the plant (yr);
- $[^{226}\text{Ra}]_{\text{g}}$ is the grid-specific concentration of ^{226}Ra on site (pCi/g);
- DRF_{j} is the job-category-specific dose-reduction or shielding factor (unitless);
- $[^{226}\text{Ra}]_{\text{b}}$ is the concentration of ^{226}Ra (pCi/g) in background soil;
- $F_{\text{g,j}}$ is the fraction of time a worker within a given job category at a given location spends outdoors while on the job (unitless);
- UCF_{t1} is a time unit conversion factor (hr/d); and,
- UCF_{t2} is an additional time unit conversion factor (d/yr).

To obtain a dose distribution for a randomly-selected member of the permanent, full-time work force, the grids were sampled randomly in proportion to the number of workers assigned to a particular location, $P_{w,g}$ and, as the dose-reduction factor and fraction of time spent outdoors varies by a worker's job assignment, in proportion to the number of workers at that location within a given job category, $P_{g,j}$.

The following subsections define and provide rationale for each of the variables and non-variable parameters listed above. The variables and parameters are discussed in the order in which they appear on the spreadsheet used to run the model (see the end of Appendix F). The final subsection summarizes the occupational exposure assessment.

2.2.1.1 Exposure Frequency and Time

The EPA typically assumes that 250 d/yr for 8.0 hr/d is the worker exposure frequency:

$$EF_{occ} \times ET_{occ} = 250 \frac{d}{yr} \times 8.0 \frac{hr}{d} = 2,000 \frac{hr}{yr}.$$

Equation 2.2.1.1-1

Site-specific data are available from a dosimetry study undertaken pursuant to the Southeast Idaho Radionuclide Project [J. Alvarez, International Technologies Corporation (Personal communication) July 27, 1994]. These data, gathered over the course of eleven weeks, do not allow for estimation of EF_{occ} and ET_{occ} separately, but do allow for the estimation of the distribution of the product of these two variables.

The following statistics derive from the time sheets for the seventeen participants in the study (converting, by straight-line extrapolation, the weekly data to an annual basis; see Appendix B):

<u>Parameter</u>	<u>Value</u>
$\mu_{EF \times ET}$	1,900 hr/yr
$\sigma_{EF \times ET}$	194 hr/yr

Assuming that the lower and upper bounds of the distribution are, by physical constraint, 0 and 8,766 hr/yr, respectively, the most uncertain distribution, as derived with maximum-entropy inference, is the beta distribution, $\beta(75, 270, 0, 8,766)$ hr/yr, where 75 is the alpha shape factor, $\alpha_{EF \times ET}$, 270 is the beta shape factor, $\beta_{EF \times ET}$, and 0 and 8,766 are the

lower and upper bounds, $\lambda_{EF \times ET}$ and $\nu_{EF \times ET}$, respectively. The shape factors are calculated using Equations 2.1.4-2 and 2.1.4-3.

The mean of this distribution is somewhat lower than the 2,000 hr/yr generated with conventional wisdom because the distribution acknowledges on-site working time only (e.g., travel, out-of-town meetings, or off-site training sessions do not result in on-site exposures); holidays are also factored into the distribution.

EPA-10 used site-specific point estimates ranging, for various materials, from 160 to 250 d/yr for their EF_{occ} component of this variable with point estimates of 1.0 to 6 hr/d for their ET_{occ} component (see Table 3-2a in SAIC, 1995). Their resulting material-specific values for $EF_{occ} \times ET_{occ}$ range from 250 to 1,080 hr/yr. Both values are, for all practical purposes, at the 0th percentile of this distribution defined above.

2.2.1.2 Exposure Duration

The EPA typically assumes that a worker spends 25 yr at a given site. Monsanto provided site-specific employment-duration data for all permanent, full-time employees who have ever worked at the Soda Springs Plant that have voluntarily or involuntarily been separated from the plant [K. Lott, Monsanto (Personal communication) February 27, 1995]. The database contains 873 such employees. The mean ED_{occ} value is 9.2 yr, the standard deviation is 10.7 yr. [For the national population, the United States Bureau of Labor Statistics (1987) estimates the mean occupational exposure duration to be 7.4 yr, with a standard deviation of 11.7 yr.] The lower and upper bounds of the database are, respectively, 0.0055 and 40 yr. However, some of the employees originally hired when the plant initiated operations in the 1950s have yet to retire. Thus, λ_{ED} is assumed to be 0 yr, and ν_{ED} is assumed to be 47 yr (the difference between retirement at age 65 and initial employment at age 18).

With estimates of the mean, standard deviation, and bounds of ED_{occ} , maximum-entropy inference can be applied to derive the following beta distribution: $\beta(0.40, 1.64, 0, 47)$ yr. EPA's standard assumption of 25 yr is at the 89th percentile of this distribution.

2.2.1.3 Time Unit Conversion Factors

The denominator of the risk model contains two unit conversion factors. They are:

- UCF_{t1} —24 hr/d; and,
- UCF_{t2} —365.25 d/yr.

2.2.1.4 Proportions of the Work Force Located in Particular Grids

The EPA-10 assessment implicitly locates an entire plant work force subpopulation at the point of interest for any given exposure scenario. For the stochastic assessment, the plant consists of 23 grids (see Figure 2.2-2); these are a subset of the 81-grid network originally established for the air quality modeling effort at the site (GAI and SENES Consultants Limited [SENES], 1995). With the constraint that the grid-specific proportions, $P_{w,g}$, must sum to unity, and assuming each permanent, full-time employee works entirely within a single grid, plant engineering and environmental managers [K. Lott and B. Geddes, Monsanto (Personal communication) September 26, 1994] estimated the distribution of employees as follows:

<u>Grid</u>	<u>$P_{w,g}$</u>
23	0.0066
24	0
25	0
33	0
34	0.0198
35	0
43	0
44	0.23
45	0.33
46	0
53	0
54	0.37
55	0
56	0
63	0
64	0.0165

<u>Grid</u>	<u>P_{w,g}</u>
65	0.0132
66	0
73	0.0066
74	0
75	0.0066
76	0
77	0

These proportions are treated deterministically within the model for the sake of computational simplification. The model thus assumes that each worker works within a single grid for his entire plant career. While many workers' jobs require them to work within more than one grid, most spend the vast majority of their time at a given station or relatively small area. To account for those jobs involving vehicle or heavy equipment operation which cross grid boundaries, certain grids with stockpiled material of interest (*e.g.*, underflow solids in grid 73) have minor work-force proportions that likely overestimate exposure opportunities.

The above estimates are fairly representative of the distribution of permanent, full-time employees throughout the plant. The effect of this simplification is likely two-fold: an under-representation of uncertainty in the risk estimate, and a conservative bias (*i.e.*, the coefficient of variation of the risk, the standard deviation divided by the mean, maybe somewhat underestimated, and the mean may be somewhat overestimated).

The above estimates of work-force proportions omit no significant stockpiles from the assessment (*i.e.*, none of the significant stockpiles, in terms of material volume or relative concentration of ^{226}Ra , are associated with a 0-proportion-of-the-work-force estimate). As grids 24, 25, 33, 35, 43, 46, 53, 55, 56, 63, 66, 74, 76, and 77 are estimated to contain a 0 proportion of the work force, there is no need, at this time, to define estimates of ^{226}Ra concentrations, proportions of job categories, and outdoor time fractions for these grids. Any subsequent effort undertaken to refine the risk model may require the definition of these variables. The effect of this simplification is likely a contribution to conservatism in the risk estimate, as the grids assumed to contain no workers are generally those with relatively lower concentrations of ^{226}Ra .

2.2.1.5 Proportions of the Within-Grid Work Forces Assigned to Particular Job Categories

The EPA-10 assessment implicitly assigns all workers on the site to a single job for each material-specific subscenario. Plant engineering and environmental managers [K. Lott and B. Geddes, Monsanto (Personal communication) September 26, 1994] estimated $P_{g,j}$, the distribution of employees over three job categories—unshielded worker (*i.e.*, a pedestrian worker when outdoors), vehicle operator, and heavy equipment operator—within each active grid, subject to the constraint that the sum for any given grid must be unity. Their results are:

<u>Grid</u>	<u>Job Category</u>	<u>$P_{g,j}$</u>
23	unshielded worker	0
	vehicle operator	1.00
	heavy equipment operator	0
34	unshielded worker	0
	vehicle operator	0
	heavy equipment operator	1.00
44	unshielded worker	1.00
	vehicle operator	0
	heavy equipment operator	0
45	unshielded worker	1.00
	vehicle operator	0
	heavy equipment operator	0
54	unshielded worker	0.95
	vehicle operator	0
	heavy equipment operator	0.050
64	unshielded worker	0
	vehicle operator	0
	heavy equipment operator	1.00
65	unshielded worker	0
	vehicle operator	0
	heavy equipment operator	1.00
73	unshielded worker	0
	vehicle operator	1.00
	heavy equipment operator	0
75	unshielded worker	0
	vehicle operator	0
	heavy equipment operator	1.00

The implicit assumption in the above approach is that each individual works not only within a single grid, but entirely within a single job category, as well. This approach is somewhat

conservative for unshielded workers, as significant shielding exists in the other two job categories. For vehicle and heavy equipment operators, this approach is somewhat non-conservative in the sense that some time is spent outdoors unshielded in transit between their vehicles or equipment and buildings; this non-conservatism, however, is probably more than compensated for by the assumption used for $F_{g,j}$ (see Subsection 2.2.1.6, below).

2.2.1.6 Grid- and Job-Specific Fractions of Time Spent Outdoors

A distribution of fractions for each active job category within each active grid, $F_{g,j}$, was developed on the basis of the judgments of plant engineering and environmental managers [K. Lott and B. Geddes, Monsanto (Personal communication) September 26, 1994]. Estimates of μ_F —in the form of a fraction of an average work day spent outdoors—were elicited and used, in conjunction with maximum-entropy inference, to develop the distributions. For each grid-and-job category, the values of λ_F and ν_F were assumed to be 0 and 1.00, respectively, on the basis of physical constraints. A standard deviation was selected, in accordance with Lee and Wright (1994), to maximize the distribution's uncertainty. The resulting estimates of this variable, for active job categories within active grids, are:

<u>Grid</u>	<u>Job Category</u>	<u>$F_{g,j}$</u>
23	vehicle operator	1.00
34	heavy equipment operator	1.00
44	unshielded worker	$\beta(0.98, 46, 0, 1.00)$
45	unshielded worker	$\beta(0.98, 46, 0, 1.00)$
54	unshielded worker	$\beta(0.88, 6.2, 0, 1.00)$
	heavy equipment operator	1.00
64	heavy equipment operator	1.00
65	heavy equipment operator	1.00
73	vehicle operator	1.00
75	heavy equipment operator	1.00

Assuming, conservatively, that vehicle operators and heavy equipment operators spend all of their time outdoors compensates for the implicit assumption that all workers work within a single job category (see Subsection 2.2.1.6). The distribution parameter assumptions that resulted in the two types of distributions included above are as follows (presented

within the units of an 8-hr work day to enhance comprehension, although the distributions themselves are unitless fractions):

- $\beta(0.98, 46, 0, 1.00)$ —
– $\mu_F = 0.167$ hr/d
- $\beta(0.88, 6.2, 0, 1.00)$ —
– $\mu_F = 1.00$ hr/d

EPA typically ignores this variable, in effect setting it to 1.00. This is the case in SAIC (1995). The implicit value of 1.00 is equal to the point estimates presented above for heavy equipment and vehicle operators; it is at the 100th percentile of both the distributions used to characterize unshielded workers.

2.2.1.7 Job-Specific Dose-Reduction Factors

The three categories of jobs used in this assessment—unshielded workers, vehicle operators, and heavy equipment operators—were designated to account for differences in the gamma-radiation shielding associated with each job type. For example, unshielded workers have virtually no shielding from gamma radiation, whereas heavy equipment operators may have a great degree of shielding because of the massive nature of their equipment.

Monsanto obtained site-specific DRF measurements for the vehicle operator and heavy equipment operator categories (the DRF for unshielded workers, DRF_{uw} , is presumably 1.00; see Appendix C for documentation of the other two DRFs, DRF_{vo} and DRF_{heo}).

The job-specific DRFs are:

<u>Job Category</u>	<u>DRF_j</u>
unshielded worker	1.00
vehicle operator	$\beta(12.4, 7.3, 0, 1.00)$
heavy equipment operator	$\beta(4.4, 11.3, 0, 1.00)$

EPA-10 used the 99th percentile of DRF_{heo} , 0.55, as their point estimate in SAIC (1995; see Table 3-2b).

2.2.1.8 Grid-Specific Concentrations of ^{226}Ra in Soil and On-Site Materials

The EPA-10 chose to represent this variable, $[^{226}\text{Ra}]$, with conservatively biased estimates of mean concentrations in various materials stockpiled on the site. These values range from 27 to 51 pCi/g (see Tables B-2b in SAIC, 1995). For the stochastic analysis, kriging the soil quality data allowed for development of grid-specific estimates of lognormal distributions of ^{226}Ra soil concentrations (see Appendix D). Materials quality data for the various stockpiles and roads at the plant (see Appendix E) allowed for development of material-specific lognormal ^{226}Ra concentration distributions.

Table 2.2.1.8-1 displays the estimation of the composition of the outdoor area of each active grid—in terms of proportion of soil, road, and stockpile materials—used in the estimation of $[^{226}\text{Ra}]_g$ (see Figure 2.2-2). The material-specific weighting factors tabulated in Table 2.2.1.8-1 are used in conjunction with material-specific ^{226}Ra concentration distributions, $[^{226}\text{Ra}]_m$, to derive $[^{226}\text{Ra}]_g$ through weighted sampling within the occupational risk model. Material-specific notation and distributions used within the model are as follows [EPA-10's point estimate and its percentile on the corresponding distribution are indicated parenthetically; see Table 3-5 of SAIC (1995)]:

- new nodules — $[^{226}\text{Ra}]_{\text{nn}}$, LN(50, 2.1) pCi/g (vs. 51 pCi/g or the 71st percentile);
- old nodules — $[^{226}\text{Ra}]_{\text{on}}$, LN(41, 1.00) pCi/g (vs. 51 pCi/g or virtually the 100th percentile);
- ore blend #1 — $[^{226}\text{Ra}]_{\text{o1}}$, LN(32, 3.5) pCi/g (not used in the EPA-10 assessment);
- ore blend #2 — $[^{226}\text{Ra}]_{\text{o2}}$, LN(29, 1.15) pCi/g (not used in the EPA-10 assessment);
- road dust — $[^{226}\text{Ra}]_{\text{rd}}$, LN(30, 1.00) pCi/g (vs. 42 pCi/g or virtually the 100th percentile);

Table 2.2.1.8-1. Composition of the Outdoor Area of the Monsanto Soda Springs Plant by Grid.

Grid:	<u>23</u>	<u>34</u>	<u>44</u>	<u>45</u>	<u>54</u>	<u>64</u>	<u>65</u>	<u>73</u>	<u>75</u>
<u>Material</u>									
new nodules					0.10				
old nodules						0.20			
ore blend #1							0.20		
ore blend #2							0.20		
roads			0.30		0.90	0.20	0.10		0.10
slag		1.00	0.70						
soil	1.00			1.00				1.00	0.10
treater dust						0.30			
underflow solids						0.30	0.50		0.80

- slag — $[^{226}\text{Ra}]_{\text{sl}}$, LN(48, 5.7) pCi/g (vs. 50 pCi/g or the 67th percentile);
- treater dust — $[^{226}\text{Ra}]_{\text{td}}$, LN(20, 6.5) pCi/g (vs. 27 pCi/g or the 86th percentile);
- underflow solids — $[^{226}\text{Ra}]_{\text{us}}$, LN(38, 3.8) pCi/g (vs. 41 pCi/g or the 80th percentile);
- baghouse dust — $[^{226}\text{Ra}]_{\text{bd}}$, LN(20, 16.0) pCi/g (vs. 32 pCi/g or the 85th percentile); and,
- soil within grid g, $[^{226}\text{Ra}]_{\text{soil,g}}$ —
 - $[^{226}\text{Ra}]_{\text{soil,23}}$, LN(2.4, 0.85) pCi/g (not used in the EPA-10 assessment);
 - $[^{226}\text{Ra}]_{\text{soil,45}}$, LN(3.7, 1.91) pCi/g (not used in the EPA-10 assessment);
 - $[^{226}\text{Ra}]_{\text{soil,73}}$, LN(5.1, 1.97) pCi/g (not used in the EPA-10 assessment); and,
 - $[^{226}\text{Ra}]_{\text{soil,75}}$, LN(5.1, 1.89) pCi/g (not used in the EPA-10 assessment).

All concentration distributions are assumed to be lognormal and are in units of pCi/g. Statistical parameters for $[^{226}\text{Ra}]_{\text{m}}$ are tabulated in Appendix E, and those for $[^{226}\text{Ra}]_{\text{soil,g}}$ in Appendix D.

An implicit assumption in this approach is that an individual is exposed equally to all portions of the grid in which he is assigned. This assumption likely contributes to a high bias in the $[^{226}\text{Ra}]_{\text{g}}$ estimates, as the materials stockpiles tend to have higher concentrations of ^{226}Ra than do the soil or roads, and individuals likely spend a disproportionate amount of outdoor time on top of soil or a road rather than on top of a stockpile.

2.2.1.9 Concentration of ^{226}Ra in Background Soil

The EPA-10 represents this variable, $[\text{}^{226}\text{Ra}]_b$, with an upper-bound estimate of the mean value, 1.90 pCi/g (see Table C-1, SAIC, 1995). The stochastic definition of this variable, LN(1.70, 0.50) pCi/g, derives empirically from the twenty soil background samples available (GAI and SENES, 1995). EPA-10's estimate of 1.90 pCi/g corresponds to the 70th percentile of LN(1.70, 0.50) pCi/g.

2.2.1.10 Exposure Assessment Summary for the Occupational Scenario

The results of the exposure assessment are summarized as follows (NA indicates not applicable):

<u>Variable</u>	<u>Deterministic Definition</u>	<u>Stochastic Definition</u>
$\text{EF}_{\text{occ}} \times \text{ET}_{\text{occ}}$	1,280 to 2,000 hr/yr	$\beta(75, 270, 0, 1.00)$ hr/yr
ED_{occ}	25 yr	$\beta(0.40, 1.64, 0, 47)$ yr
UCF_{t1}	24 hr/d	24 hr/d
UCF_{t2}	365.25 d/yr	365.25 d/yr
$\text{P}_{\text{w,g}}$	1.00	
grid 23		0.0066
grid 34		0.0198
grid 44		0.23
grid 45		0.33
grid 54		0.37
grid 64		0.0165
grid 65		0.0132
grid 73		0.0066
grid 75		0.0066
all other grids		0
$\text{P}_{\text{g,j}}$	1.00	
grid 23		
vehicle operators		1.00
grid 34		
heavy equipment operators		1.00
grid 44		
unshielded workers		1.00

<u>Variable</u>	<u>Deterministic Definition</u>	<u>Stochastic Definition</u>
$P_{g,j}$, continued		
grid 45 unshielded workers		1.00
grid 54 unshielded workers		0.95
heavy equipment operators		0.050
grid 64 heavy equipment operators		1.00
grid 65 heavy equipment operators		1.00
grid 73 vehicle operators		1.00
grid 75 heavy equipment operators		1.00
jobs not specified in above grids		0
all other grids		NA
$F_{g,j}$	1.00	
grid 23 vehicle operators		1.00
grid 34 heavy equipment operators		1.00
grid 44 unshielded workers		$\beta(0.98, 46, 0, 1.00)$
grid 45 unshielded workers		$\beta(0.98, 46, 0, 1.00)$

<u>Variable</u>	<u>Deterministic Definition</u>	<u>Stochastic Definition</u>
$F_{g,j}$, continued		
grid 54		
unshielded workers		$\beta(0.88, 6.2, 0, 1.00)$
heavy equipment operators		1.00
grid 64		
heavy equipment operators		1.00
grid 65		
heavy equipment operators		1.00
grid 73		
vehicle operators		1.00
grid 75		
heavy equipment operators		1.00
jobs not specified in above grids		NA
all other grids		NA
DRF_j	0.55	
unshielded workers		1.00
vehicle operators		$\beta(12.4, 7.3, 0, 1.00)$
heavy equipment operators		$\beta(4.4, 11.3, 0, 1.00)$
$[^{226}\text{Ra}]_m$	27 to 51 pCi/g	
new nodules		LN(50, 2.1) pCi/g
old nodules		LN(41, 1.00) pCi/g
ore blend #1		LN(32, 3.5) pCi/g
ore blend #2		LN(29, 1.15) pCi/g
road dust		LN(30, 1.00) pCi/g
slag		LN(48, 5.7) pCi/g
soil		
grid 23		LN(2.4, 0.85) pCi/g
grid 45		LN(3.7, 1.91) pCi/g
grid 73		LN(5.1, 1.89) pCi/g
grid 75		LN(5.1, 1.97) pCi/g
all other grids		NA

<u>Variable</u>	<u>Deterministic Definition</u>	<u>Stochastic Definition</u>
$[^{226}\text{Ra}]_m$, continued		
treater dust		LN(20, 6.5) pCi/g
underflow solids		LN(38, 3.8) pCi/g
baghouse dust		LN(20, 16.0) pCi/g
$[^{226}\text{Ra}]_b$	1.90 pCi/g	LN(1.70, 0.50) pCi/g

No significant correlation is expected between any of the exposure and toxicity variables. The only expected correlation among the exposure variables is between ED_{occ} and $EF_{occ} \times ET_{occ}$, because the longer an individual is employed, the less time is actually spent on the job due to increases in earned vacation time. This negative correlation is assumed to be moderate in magnitude (*i.e.*, $r^2 \approx 0.50$); therefore, a correlation coefficient, r , of -0.71 is imposed between ED_{occ} and $EF_{occ} \times ET_{occ}$. This is the only correlation used in the occupational model.

2.2.2 Residential Scenario

The exposure assessment for this scenario is presented in two parts: Subsection 2.2.2.1 presents the assessment for the current subscenario, and Subsection 2.2.2.2 presents the assessment for the future subscenario.

2.2.2.1 Current Residential Subscenario

The exposure assessment for current residents is conducted on a location-specific basis to account for spatial heterogeneity in As concentrations and the distribution of residences in the near vicinity of the Monsanto plant. The dose equation used is:

$$D_{cres,g} = \frac{\text{IngR}_{s/d} \times EF_{res} \times ED_{res} \times ([As]_g - [As]_b) \times BF_{s,As} \times F_s \times F_1 \times UCF_m}{BW \times AT \times UCF_{t2}} \quad \text{Equation 2.2.2.1-1}$$

where:

- $D_{cres,g}$ is the current residential, grid-specific dose [mg/(kg·d)];
- $\text{IngR}_{s/d}$ is the soil and dust (*i.e.*, dirt) ingestion rate (mg/d);

- EF_{res} is the residential exposure frequency (d/yr);
- ED_{res} is the residential exposure duration (yr);
- $[As]_g$ is the grid-specific concentration of As in soil (mg/kg);
- $[As]_b$ is the concentration of As (mg/kg) in background soil;
- $BF_{s,As}$ is the bioavailability factor for As in soil (unitless);
- F_s is the fraction of ingested dirt that is derived from soil (unitless);
- F_l is the fraction of time spent locally at the residence (unitless);
- UCF_m is a mass unit conversion factor (kg/mg);
- BW is the resident's body weight (kg);
- AT is the averaging time (*i.e.*, an average life span, yr); and,
- UCF_{t2} is the second time unit conversion factor used in the occupational exposure submodel (d/yr).

To obtain a dose distribution for a randomly-selected member of the residential population in the near vicinity of the plant, the grids were sampled randomly in proportion to the number of residences in a particular location, $P_{r,g}$.

The following paragraphs define and provide rationale for each of the variables and non-variable parameters listed above. The variables and parameters are discussed in the order in which they appear on the spreadsheet used to run the model (see the end of Appendix L). The final paragraph summarizes the current residential exposure assessment.

2.2.2.1.1 Soil and Dust Ingestion Rate. EPA-10 assumes a value of 120 mg/d for $IngR_{s/d}$, based on a weighted average of assumed child and adult values (SAIC, 1995). Stochastically, this variable is represented by LN(91, 126) mg/d. This distribution was published by Thompson and Burmaster (1991) and applies to children. Thus, the

distribution undoubtedly creates a conservative bias when used, as in the current residential exposure submodel, to represent $\text{IngR}_{s/d}$ for the general population. EPA-10's standard assumption of 120 mg/d corresponds to the 78th percentile of $\text{LN}(91, 126)$ mg/d.

2.2.2.1.2 Fraction of Ingested Soil and Dust That is Soil. EPA-10, by not including this variable in their corresponding model, implicitly assumes that 100% of ingested dirt is soil (SAIC, 1995). In the current residential exposure submodel, F_s is represented by $\beta(0.99, 1.03, 0, 1.00)$, based on a mean of 0.48 and standard deviation of 0.29 obtained from data provided by Stanek and Calabrese (1992) (0 and 1.00 are set as lower and upper bounds on the basis of physical constraint). These data are specific to children; thus, their use may contribute to a conservative bias as adults may, on average, consume less soil. EPA-10's implicit assumption of 1.00 corresponds to the 100th percentile of $\beta(0.99, 1.03, 0, 1.00)$.

2.2.2.1.3 Fraction of Time Spent Locally. This variable is not contained in EPA-10's model (SAIC, 1995), and is thus implicitly set at 1.00. Given that not all individuals spend 100% of their time at their residence, $U(0, 1.00)$ is used in the current residential exposure submodel. This distribution is based on maximum-entropy inference applied to the lower and upper bounds derived from physical constraints. EPA-10's implicit assumption corresponds to the 100th percentile of $U(0, 1.00)$.

2.2.2.1.4 Bioavailability Factor for As in Soil. As EPA-10's model does not contain this variable, they implicitly assume that all ingested As is absorbed. On the basis of a mean value of 0.090 obtained by use of the physiological relevant extraction procedure on soils for a site in British Columbia (CB Research International, 1993), and assuming that lower and upper bounds, on the basis of physical constraint, are 0 and 1.00, Equations 2.1.4-1 through 2.1.4-3 are used to yield the following broad distribution— $\beta(0.91, 9.2, 0, 1.00)$. (The standard deviation obtained from the CB Research International data was intentionally not used so as to broaden the distribution to account for likely site-specific differences in this variable.) EPA-10's implicit assumption of 1.00 corresponds to the 100th percentile of the distribution defined above.

2.2.2.1.5 Exposure Frequency. EPA-10 assumes that residential exposures occur 350 d/yr (SAIC, 1995). Assuming that this value represents the mean of the EF_{res} distribution, and that the lower and upper bounds are 0 and 365.25 d/yr on the basis of physical constraint, a beta distribution, $\beta(21, 0.92, 0, 365.25)$ d/yr, is developed using

Equations 2.1.4-1 through 2.1.4-3. EPA-10's assumption of 350 d/yr is at the 37th percentile of the corresponding distribution.

2.2.2.1.6 Exposure Duration. Residential exposure duration, ED_{res} , is based on data provided by Israeli and Nelson (1991). These data yield a mean value of 4.6 yr and a standard deviation of 8.7 yr. A lognormal distribution is used, $LN(4.6, 8.7)$ yr. EPA-10 assumed a duration of 30 yr (SAIC, 1995), which is at the 98th percentile of the distribution.

2.2.2.1.7 Mass Unit Conversion Factor. The unit conversion factor in the numerator of the submodel is UCF_m , which is 0.00000100 kg/mg.

2.2.2.1.8 Body Weight. The default assumption for average lifetime body weight used by EPA-10 is 59 kg, a weighted average of child and adult median body weight estimates. For this assessment, BW is represented as $LN(58, 22)$ kg, which is derived from normal distributions developed from data provided in EPA (1990). Data for female and male children, youths, and adults were used to develop normal distributions which were then sampled randomly—in proportion to an assumed demographic profile of 8.0% children, 32% youths, and 60% adults, equally proportioned between females and males—to generate an estimate for the general population. EPA-10's assumption of 59 kg is at the 59th percentile of $LN(58, 22)$ kg.

2.2.2.1.9 Averaging Time. The EPA assumes that the average human life span is 70 yr. This assumption, although it is somewhat low and thus contributes to a conservative bias in the assessment (given that this parameter is located in the denominator), is used without modification.

2.2.2.1.10 Time Unit Conversion Factor. The value of UCF_{t2} is identical to that used in the occupational exposure submodel—365.25 d/yr.

2.2.2.1.11 Proportions of Residential Population Located in Particular Grids. Only two grids on Figure 2.2-1 contain residences—31 and 41, which are located to the west of the plant. Thus, $P_{r,g}$ for each is set at 0.50, and at 0 for each of the other 79 grids. EPA-10 evaluated this western location along with locations to the south and north of the plant, and each subpopulation was evaluated separately. The locations to the south and north are not

currently inhabited. The stochastic model gives no weight to these locations under this subscenario.

2.2.2.1.12 Grid-Specific Concentrations of As in Soil. Kriging (see Appendix D) was used to develop grid-specific estimates of arsenic concentrations in soil, $[As]_g$. The results, for all 81 grids, are provided in Appendix K. However, per Paragraph 2.2.2.1.11, the results for grids 31 and 41 are the only two that are relevant. $[As]_{31}$ is LN(3.9, 2.7) mg/kg, and $[As]_{41}$ is LN(3.3, 1.95) mg/kg. EPA-10 assumes that this value ranges from within background (see Paragraph 2.2.2.1.13, below) to 9.0 mg/kg (see Tables B-4a through B-4c, SAIC, 1995). At the western locations (which closely correspond to grids 31 and 41), EPA-10 notes that the concentration of As in soil is less than 4.4 mg/kg. This value corresponds to the 69th percentile of the distribution for $[As]_{31}$, and the 79th percentile of the distribution for $[As]_{41}$.

2.2.2.1.13 Concentration of As in Background Soil. Based on twenty background soil samples, $[As]_b$ is LN(4.0, 0.85) mg/kg (GAI and SENES, 1995). The value used by EPA-10 is 4.4 mg/kg (see Table C-3, SAIC, 1995). EPA-10's value corresponds to the 72nd percentile of the distribution for $[As]_b$.

2.2.2.1.14 Exposure Assessment Summary for the Current Residential Subscenario. The results of the exposure assessment are summarized below:

<u>Variable</u>	<u>Deterministic Definition</u>	<u>Stochastic Definition</u>
$IngR_{s/d}$	120 mg/d	LN(91, 126) mg/d
F_s	1.00	$\beta(0.99, 1.03, 0, 1.00)$
F_l	1.00	U(0, 1.00)
$BF_{s,As}$	1.00	$\beta(0.91, 9.2, 0, 1.00)$
EF_{res}	350 d/yr	$\beta(21, 0.92, 0, 365.25)$ d/yr
ED_{res}	30 yr	LN(4.6, 8.7) yr
UCF_m	0.00000100 kg/mg	0.00000100 kg/mg
BW	59 kg	LN(58, 22) kg
AT	70 yr	70 yr
UCF_{t2}	365.25 d/yr	365.25 d/yr
$P_{r,g}$	1.00	
	grid 31	0.50
	grid 41	0.50
	all other grids	0

<u>Variable</u>	<u>Deterministic Definition</u>	<u>Stochastic Definition</u>
[As] _g	< 4.4 to 9.0 mg/kg	
grid 31		LN(3.9, 2.7) mg/kg
grid 41		LN(3.3, 1.95) mg/kg
all other grids		NA
[As] _b	4.4 mg/kg	LN(4.0, 0.85) mg/kg

No significant correlation is expected between any of the exposure and toxicity variables. Several correlations, however, have been specified among exposure variables.

IngR_{s/d} is assumed to be moderately and negatively correlated with BW (*i.e.*, $r^2 \approx 0.50$, and $r \approx -0.71$), as younger, thus smaller, individuals (*i.e.*, children) are assumed to ingest more dirt. IngR_{s/d} is also assumed to be moderately and positively correlated with F_s ($r \approx 0.71$), the logic being that children are assumed to ingest relatively more soil as opposed to dust. BW is also assumed to be weakly and negatively correlated with ED_{res} and EF_{res} (*i.e.*, $r^2 \approx 0.25$, and $r \approx -0.50$), based on the assumptions that children have the opportunity to live in given location longer, and that they spend more time at home (*i.e.*, less time traveling away from home).

2.2.2.2 Future Residential Subscenario

This subscenario is also conducted on a location-specific basis, because of spatial heterogeneity in ²²⁶Ra and receptor distributions. The exposure submodel for this subscenario is:

$$D_{\text{fres,g}} = \frac{\text{EF}_{\text{res}} \times \text{ED}_{\text{res}} \times \left[\left([^{226}\text{Ra}]_{\text{g}} \times \text{TSGF} \times \text{DRF} \right) - [^{226}\text{Ra}]_{\text{b}} \right] \times F_o \times F_l}{\text{UCF}_{\text{t2}}}$$

Equation 2.2.2.2-1

where:

- D_{fres,g} is the future residential, grid-specific dose [pCi·yr/(kg·g)];
- EF_{res} is the residential exposure frequency (d/yr);
- ED_{res} is the residential exposure duration (yr);
- [²²⁶Ra]_g is the grid-specific concentration of ²²⁶Ra in soil (pCi/g);

- TSGF is the thin-shell geometry factor (unitless);
- DRF is the gamma radiation dose-reduction, or shielding, factor (unitless);
- $[^{226}\text{Ra}]_b$ is the concentration of ^{226}Ra (pCi/g) in background soil;
- F_o is the fraction of time spent outdoors where exposure can occur (unitless);
- F_l is the fraction of time spent locally at the residence (unitless); and,
- UCF_{12} is a time unit conversion factor (d/yr).

To obtain a dose distribution for a randomly selected member of the future residential population in the near vicinity of the plant, the grids were sampled randomly in proportion to the number of residences in a particular location, $P_{r,g}$.

The following paragraphs define and provide rationale for each of the variables and non-variable parameters listed above. The variables and parameters are discussed in the order in which they appear on the spreadsheet used to run the model (see the end of Appendix N). The final paragraph summarizes the future residential exposure assessment.

2.2.2.2.1 Exposure Frequency. EF_{res} is defined the same as it is in the current subscenario— $\beta(21, 0.92, 0, 365.25)$ d/yr (see Paragraph 2.2.2.1.5).

2.2.2.2.2 Exposure Duration. ED_{res} is defined the same as it is in the current subscenario— $\text{LN}(4.6, 8.7)$ yr (see Paragraph 2.2.2.1.6).

2.2.2.2.3 Fraction of Time Spent Outdoors. GCA Corporation (1985) reports that people, on average, spend 7.4% of their time outdoors. Given this estimate of the mean, and setting the lower and upper bounds at 0 and 1.00 on the basis of physical constraint, Equations 2.1.4-1 through 2.1.4-3 can be used, pursuant to maximum-entropy inference, to derive an uncertain beta distribution— $\beta(0.92, 11.6, 0, 1.00)$. The corresponding EPA-10 model omits this variable (SAIC, 1995), which results in an implicit assumption of

1.00, or 100% of time being spent outdoors. The value of 1.00 lies at the 100th percentile of the defined distribution.

2.2.2.2.4 Fraction of Outdoor Time Spent Locally. Because not everyone spends all of their time at their residence, even when they are not on vacation, $U(0, 1.00)$ is used to account for time spent elsewhere. This was derived through maximum-entropy inference applied to lower and upper bounds based on physical constraints. The EPA-10 (SAIC, 1995) omits this variable, thereby assuming that all non-vacation time is spent at the residence. EPA-10's implicit assumption of 1.00 is at the 100th percentile of $U(0, 1.00)$.

2.2.2.2.5 Time Unit Conversion Factor. UCF_{t2} is identical to that used in the current subscenario—365.25 d/yr.

2.2.2.2.6 Proportions of Residential Population Located in Particular Grids. $P_{r,g}$ is defined on the basis of land use, zoning, and property ownership of the area within the receptor grid network (see Figure 2.2-1). Five categories of potential future residential use are defined:

<u>Future-Use Category</u>	<u>Relative Likelihood of Development</u>
Non-residential, currently industrial, commercial, park, or owned by Monsanto	0
Low-density residential/ agricultural, currently undeveloped	1.00
Low-density residential, currently undeveloped	10.0
Low-density residential, currently developed	100
High-density residential, currently undeveloped	1,000

Each of the 81 grids in the receptor network was classified, on a quarter-grid level of resolution, by the five categories listed above. The results are shown in Table 2.2.2.2.6-1. The sum of the number of grids included in each category was multiplied by the respective relative likelihood of future residential development to develop a weighting factor for a given grid that predicts the future proportion of the nearby residential population that will inhabit that grid, or $P_{r,g}$. Thus, for example, a grid that is completely classified as low-

Table 2.2.2.2.6-1. Land-Use Evaluation for the Monsanto Plant and Vicinity.

Grid	Proportional Land Use					Pr,g
	NR	RHD-U	RLD-D	RLD-U	RLD/Ag-U	
1	0	0	0	1.00	0	0.0134
2	1.00	0	0	0	0	0
3	0.50	0	0	0	0.50	0.00067
4	0	0	0	0	1.00	0.00134
5	0.75	0.25	0	0	0	0.33
6	0.25	0.25	0	0.50	0	0.34
7	1.00	0	0	0	0	0
8	0	0	0	1.00	0	0.0134
9	0	0	0	0.75	0.25	0.0104
11	0	0	0	1.00	0	0.0134
12	1.00	0	0	0	0	0
13	0.75	0	0	0	0.25	0.00033
14	0.50	0	0	0	0.50	0.00067
15	1.00	0	0	0	0	0
16	0.50	0	0	0.25	0.25	0.0037
17	0.75	0	0	0	0.25	0.00033
18	0	0	0	1.00	0	0.0134
19	0	0	0	0.75	0.25	0.0104
21	0	0	0	1.00	0	0.0134
22	0.50	0	0	0	0.50	0.00067
23	0.75	0	0	0	0.25	0.00033
24	1.00	0	0	0	0	0
25	0.75	0	0	0	0.25	0.00033
26	0.25	0	0	0	0.75	0.00100
27	0	0	0	0.25	0.75	0.0043
28	0	0	0	1.00	0	0.0134
29	0	0	0	0.75	0.25	0.0104
31	0.25	0	0.25	0	0.50	0.034
32	0	0	0	0	1.00	0.00134
33	0.50	0	0	0	0.50	0.00067
34	1.00	0	0	0	0	0
35	0.50	0	0	0	0.50	0.00067
36	0	0	0	0	1.00	0.00134
37	0	0	0	0.25	0.75	0.0043
38	0	0	0	0.75	0.25	0.0104
39	0	0	0	1.00	0	0.0134
41	0	0	0.25	0	0.75	0.034
42	0	0	0	0	1.00	0.00134
43	0.50	0	0	0	0.50	0.00067
44	1.00	0	0	0	0	0
45	1.00	0	0	0	0	0
46	0.75	0	0	0	0.25	0.00033
47	0.75	0	0	0	0.25	0.00033
48	0.25	0	0	0.25	0.50	0.0040
49	0	0	0	1.00	0	0.0134
51	0	0	0	0	1.00	0.00134
52	0	0	0	0	1.00	0.00134
53	0.50	0	0	0	0.50	0.00067
54	1.00	0	0	0	0	0

Table 2.2.2.6-1. Land-Use Evaluation for the Monsanto Plant and Vicinity, continued.

Grid	Proportional Land Use					Pr,g
	NR	RHD-U	RLD-D	RLD-U	RLD/Ag-U	
55	1.00	0	0	0	0	0
56	0.75	0	0	0	0.25	0.00033
57	0.50	0	0	0	0.50	0.00067
58	0	0	0	0.25	0.75	0.0043
59	0	0	0	0.25	0.75	0.0043
61	0	0	0	0	1.00	0.00134
62	0	0	0	0	1.00	0.00134
63	0.50	0	0	0	0.50	0.00067
64	1.00	0	0	0	0	0
65	1.00	0	0	0	0	0
66	0.50	0	0	0	0.50	0.00067
67	0	0	0	0	1.00	0.00134
68	0	0	0	0	1.00	0.00134
69	0	0	0	0	1.00	0.00134
71	0	0	0	0	1.00	0.00134
72	0	0	0	0	1.00	0.00134
73	0.25	0	0	0	0.75	0.00100
74	0.50	0	0	0	0.50	0.00067
75	0.50	0	0	0	0.50	0.00067
76	0.50	0	0	0	0.50	0.00067
77	0	0	0	1.00	0	0.0134
78	0	0	0	1.00	0	0.0134
79	0	0	0	1.00	0	0.0134
81	0	0	0	0	1.00	0.00134
82	0	0	0	0	1.00	0.00134
83	0	0	0	0	1.00	0.00134
84	0	0	0	0	1.00	0.00134
85	0	0	0	0	1.00	0.00134
86	0	0	0	0	1.00	0.00134
87	0	0	0	0	1.00	0.00134
88	0	0	0	0	1.00	0.00134
89	0	0	0	0	1.00	0.00134

NR: non-residential

RHD-U: high-density residential, currently undeveloped

RLD-D: low-density residential, currently developed

RLD-U: low-density residential, currently undeveloped

RLD/Ag-U: low-density residential/agricultural, currently undeveloped

density residential/agricultural, currently undeveloped is predicted to contain 0.134% of the future residential population in the near vicinity of the plant (see Table 2.2.2.2.6-1). The EPA-10 assessment implicitly assumes a $P_{r,g}$ of 1.00 at each location evaluated and evaluated each location as a separate subpopulation.

2.2.2.2.7 Grid-Specific Concentrations of ^{226}Ra in Soil. $^{226}\text{Ra}_g$ kriging results are tabulated in Appendix M. The concentrations are assumed to be lognormally distributed within each grid. Distributions for those grids containing a non-zero $P_{r,g}$ are listed below:

<u>Grid</u>	<u>$^{226}\text{Ra}_g$ (pCi/g)</u>
1	LN(1.45, 1.00)
3	LN(1.22, 0.58)
4	LN(1.35, 0.66)
5	LN(1.42, 0.76)
6	LN(1.42, 0.80)
8	LN(1.48, 0.94)
9	LN(1.55, 1.18)
11	LN(1.34, 0.83)
13	LN(1.58, 0.68)
14	LN(1.92, 0.78)
16	LN(1.53, 0.74)
17	LN(1.33, 0.60)
18	LN(1.36, 0.68)
19	LN(1.45, 0.93)
21	LN(1.34, 0.77)
22	LN(1.64, 0.73)
23	LN(2.4, 0.85)
25	LN(3.0, 1.27)
26	LN(2.1, 1.01)
27	LN(1.59, 0.80)
28	LN(1.45, 0.81)
29	LN(1.39, 0.83)
31	LN(1.34, 0.71)
32	LN(1.93, 0.93)
33	LN(2.7, 1.16)
35	LN(3.3, 1.54)

<u>Grid</u>	<u>[²²⁶Ra]_g (pCi/g)</u>
36	LN(2.4, 1.17)
37	LN(1.85, 0.96)
38	LN(1.61, 0.96)
39	LN(1.38, 0.78)
41	LN(1.62, 0.93)
42	LN(2.2, 1.16)
43	LN(3.3, 1.60)
46	LN(2.9, 1.48)
47	LN(2.2, 1.27)
48	LN(1.74, 1.08)
49	LN(1.55, 0.96)
51	LN(1.52, 0.79)
52	LN(2.4, 1.24)
53	LN(3.5, 1.73)
56	LN(3.0, 1.52)
57	LN(2.2, 1.22)
58	LN(1.78, 1.02)
59	LN(1.58, 0.91)
61	LN(1.78, 0.99)
62	LN(2.8, 1.35)
63	LN(4.8, 2.0)
66	LN(2.9, 1.27)
67	LN(2.0, 1.00)
68	LN(1.58, 0.75)
69	LN(1.53, 0.80)
71	LN(1.52, 0.76)
72	LN(2.8, 1.23)
73	LN(5.1, 1.97)
74	LN(5.6, 2.2)
75	LN(5.1, 1.89)
76	LN(3.0, 1.12)
77	LN(1.68, 0.74)
78	LN(1.33, 0.64)
79	LN(1.35, 0.70)
81	LN(1.56, 0.84)

<u>Grid</u>	<u>[²²⁶Ra]_g (pCi/g)</u>
82	LN(1.98, 0.87)
83	LN(3.2, 1.47)
84	LN(3.7, 1.67)
85	LN(3.2, 1.27)
86	LN(2.2, 0.98)
87	LN(1.24, 0.53)
88	LN(1.11, 0.49)
89	LN(1.25, 0.64)

The EPA-10 assessment used concentrations ranging from below background to 13 pCi/g (see Tables B-4d through B-4g, SAIC, 1995). EPA-10's southern I location is located within non-residential land. The agency's southern II location best corresponds to grid 5. EPA-10's point estimate concentration for this location is less than 1.90 pCi/g, which corresponds to the 80th percentile of the distribution for grid 5. The northern I location best corresponds to grid 74, where the point estimate of 13 pCi/g corresponds to the 99th percentile. The northern II location best corresponds to grid 82, where the point estimate of 2.5 pCi/g is at virtually the 100th percentile.

2.2.2.2.8 Thin-Shell Geometry Factor. TSGF is defined by means of linear regression, as documented in Appendix P. TSGF is required to correct for the eolian deposits of ²²⁶Ra in soil near the plant are not infinitely thick. Unless this correction is made, the dose of gamma radiation can be significantly overestimated. TSGF and [²²⁶Ra]_g are strongly and negatively correlated with one another ($r = -0.85$). Because of this, TSGF can be expressed as:

$$\text{TSGF} = (m_{\text{TSGF}} \times [\text{}^{226}\text{Ra}]_g) + b_{\text{TSGF}}.$$

Equation 2.2.2.2.9-1

where:

- m_{TSGF} is the slope of the line; and,
- b_{TSGF} is the line intercept.

The uncertainty in the relationship (the correlation is less than perfect) is accounted for by defining m and b as distributions on the basis of the regression statistics. As noted in Appendix P, m_{TSGF} is $N(-0.050, 0.0049)$ g/pCi, and b_{TSGF} is $N(0.97, 0.026)$ and is unitless. The notation $N(\mu, \sigma)$ denotes a normal distribution with specified mean and standard deviation. The EPA-10 assessment implicitly assumes a TSGF of 1.00, which is a valid approximation only within the range of background (see Figure P-1 in Appendix P).

2.2.2.2.9 Concentration of ^{226}Ra in Background Soil. $[^{226}\text{Ra}]_b$ is defined identically to the corresponding variable in the occupational scenario— $\text{LN}(1.70, 0.50)$ pCi/g (see Subsection 2.2.1.10).

2.2.2.2.10 Exposure Assessment Summary for the Future Residential Subscenario. The results of the exposure assessment are summarized below:

<u>Variable</u>	<u>Deterministic Definition</u>	<u>Stochastic Definition</u>
EF_{res}	350 d/yr	$\beta(21, 0.92, 0, 365.25)$ d/yr
ED_{res}	30 yr	$\text{LN}(4.6, 8.7)$ yr
F_o	1.00	$\beta(0.92, 11.6, 0, 1.00)$
F_l	1.00	$U(0, 1.00)$
BW	59 kg	$\text{LN}(58, 22)$ kg
UCF_{t2}	365.25 d/yr	365.25 d/yr
$P_{r,g}$	1.00	
grid 1		0.0134
grid 3		0.00067
grid 4		0.00134
grid 5		0.33
grid 6		0.34
grid 8		0.0134
grid 9		0.0104
grid 11		0.0134
grid 13		0.00033
grid 14		0.00067
grid 16		0.0037
grid 17		0.00033
grid 18		0.0134
grid 19		0.0104
grid 21		0.0134
grid 22		0.00067
grid 23		0.00033
grid 25		0.00033
grid 26		0.00100
grid 27		0.0043
grid 28		0.0134

<u>Variable</u>	<u>Deterministic Definition</u>	<u>Stochastic Definition</u>
$P_{r,g}$, continued		
grid 29		0.0104
grid 31		0.034
grid 32		0.00134
grid 33		0.00067
grid 35		0.00067
grid 36		0.00134
grid 37		0.0043
grid 38		0.0104
grid 39		0.0134
grid 41		0.034
grid 42		0.00134
grid 43		0.00067
grid 46		0.00033
grid 47		0.00033
grid 48		0.0040
grid 49		0.0134
grid 51		0.00134
grid 52		0.00134
grid 53		0.00067
grid 56		0.00033
grid 57		0.00067
grid 58		0.0043
grid 59		0.0043
grid 61		0.00134
grid 62		0.00134
grid 63		0.00067
grid 66		0.00067
grid 67		0.00134
grid 68		0.00134
grid 69		0.00134
grid 71		0.00134
grid 72		0.00134
grid 73		0.00100
grid 74		0.00067
grid 75		0.00067
grid 76		0.00067
grid 77		0.0134
grid 78		0.0134
grid 79		0.0134
grid 81		0.00134
grid 82		0.00134
grid 83		0.00134
grid 84		0.00134
grid 85		0.00134
grid 86		0.00134
grid 87		0.00134
grid 88		0.00134
grid 89		0.00134
all other grids		0

<u>Variable</u>	<u>Deterministic Definition</u>	<u>Stochastic Definition</u>
$[^{226}\text{Ra}]_g$	< 1.90 to 13.0 pCi/g	
grid 1		LN(1.45, 1.00) pCi/g
grid 3		LN(1.22, 0.58) pCi/g
grid 4		LN(1.35, 0.66) pCi/g
grid 5		LN(1.42, 0.76) pCi/g
grid 6		LN(1.42, 0.80) pCi/g
grid 8		LN(1.48, 0.94) pCi/g
grid 9		LN(1.55, 1.18) pCi/g
grid 11		LN(1.34, 0.83) pCi/g
grid 13		LN(1.58, 0.68) pCi/g
grid 14		LN(1.92, 0.78) pCi/g
grid 16		LN(1.53, 0.74) pCi/g
grid 17		LN(1.33, 0.60) pCi/g
grid 18		LN(1.36, 0.68) pCi/g
grid 19		LN(1.45, 0.93) pCi/g
grid 21		LN(1.34, 0.77) pCi/g
grid 22		LN(1.64, 0.73) pCi/g
grid 23		LN(2.4, 0.85) pCi/g
grid 25		LN(3.0, 1.27) pCi/g
grid 26		LN(2.1, 1.01) pCi/g
grid 27		LN(1.59, 0.80) pCi/g
grid 28		LN(1.45, 0.81) pCi/g
grid 29		LN(1.39, 0.83) pCi/g
grid 31		LN(1.34, 0.71) pCi/g
grid 32		LN(1.93, 0.93) pCi/g
grid 33		LN(2.7, 1.16) pCi/g
grid 35		LN(3.3, 1.54) pCi/g
grid 36		LN(2.4, 1.17) pCi/g
grid 37		LN(1.85, 0.96) pCi/g
grid 38		LN(1.61, 0.96) pCi/g
grid 39		LN(1.38, 0.78) pCi/g
grid 41		LN(1.62, 0.93) pCi/g
grid 42		LN(2.2, 1.16) pCi/g
grid 43		LN(3.3, 1.60) pCi/g
grid 46		LN(2.9, 1.48) pCi/g
grid 47		LN(2.2, 1.27) pCi/g
grid 48		LN(1.74, 1.08) pCi/g
grid 49		LN(1.55, 0.96) pCi/g
grid 51		LN(1.52, 0.79) pCi/g
grid 52		LN(2.4, 1.24) pCi/g
grid 53		LN(3.5, 1.73) pCi/g
grid 56		LN(3.0, 1.52) pCi/g
grid 57		LN(2.2, 1.22) pCi/g
grid 58		LN(1.78, 1.02) pCi/g
grid 59		LN(1.58, 0.91) pCi/g
grid 61		LN(1.78, 0.99) pCi/g
grid 62		LN(2.8, 1.35) pCi/g
grid 63		LN(4.8, 2.0) pCi/g
grid 66		LN(2.9, 1.27) pCi/g
grid 67		LN(2.0, 1.00) pCi/g
grid 68		LN(1.58, 0.75) pCi/g
grid 69		LN(1.53, 0.80) pCi/g

<u>Variable</u>	<u>Deterministic Definition</u>	<u>Stochastic Definition</u>
<u>[²²⁶Ra]_g, continued</u>		
grid 71		LN(1.52, 0.76) pCi/g
grid 72		LN(2.8, 1.23) pCi/g
grid 73		LN(5.1, 1.97) pCi/g
grid 74		LN(5.6, 2.2) pCi/g
grid 75		LN(5.1, 1.89) pCi/g
grid 76		LN(3.0, 1.12) pCi/g
grid 77		LN(1.68, 0.74) pCi/g
grid 78		LN(1.33, 0.64) pCi/g
grid 79		LN(1.35, 0.70) pCi/g
grid 81		LN(1.56, 0.84) pCi/g
grid 82		LN(1.98, 0.87) pCi/g
grid 83		LN(3.2, 1.47) pCi/g
grid 84		LN(3.7, 1.67) pCi/g
grid 85		LN(3.2, 1.27) pCi/g
grid 86		LN(2.2, 0.98) pCi/g
grid 87		LN(1.24, 0.53) pCi/g
grid 88		LN(1.11, 0.49) pCi/g
grid 89		LN(1.25, 0.64) pCi/g
all other grids		NA
TSGF	1.00	$N(-0.050, 0.0049) \text{ g/pCi} \times$ $[^{226}\text{Ra}]_{\text{g}} \text{ pCi/g} +$ $N(0.097, 0.026)$
<u>[²²⁶Ra]_b</u>	1.90 pCi/g	LN(1.70, 0.50) pCi/g

No significant correlation is expected between any of the exposure and toxicity variables. Several correlations, however, have been specified among exposure variables.

EF_{res} is assumed to be weakly and positively correlated with F_1 (*i.e.*, $r^2 \approx 0.25$, and $r \approx 0.50$), under the assumption that people who do not leave town that often also spend more time at their place of residence. EF_{res} is also assumed to be weakly and negatively correlated with BW (*i.e.*, $r^2 \approx 0.25$, and $r \approx -0.50$), based on the assumption that younger, and thus smaller, individuals spend more time at home. ED_{res} is assumed to be weakly and negatively correlated with BW, given that younger individuals have more potential to reside longer at a given location. And, F_1 and BW are assumed to be weakly and negatively correlated, based on the assumption that younger individuals are more likely to spend their outdoor time at their residence. The correlation between TSGF and $[^{226}\text{Ra}]_{\text{g}}$ ($r = -0.85$) is accounted for in the structure of the equation for TSGF.

Chapter 3



MONTGOMERY WATSON

3 Risk Characterization

The risk characterization phase of a risk assessment consists of two steps, risk estimation and risk description. Risk estimation is the integration of the toxicity and exposure components of the risk model and an analysis of uncertainty. Risk description is a summary and interpretation of the estimated risk. Subchapter 3.1 documents the risk characterization phase for the occupational scenario; Subchapter 3.2 documents the risk characterization phase for the residential scenario.

3.1 Occupational Scenario

Risk estimation results for the occupational scenario at Monsanto's Soda Springs Plant are presented in Section 3.1.1. The risk estimates are described in Section 3.1.2.

3.1.1 Risk Estimation

Toxicity and exposure submodels are integrated to generate risk estimates. The results of this integration are presented below in Subsection 3.1.1.1. The uncertainties associated with the risk estimate are discussed in Subsection 3.1.1.2.

For on-site workers, SAIC (1995) documents an absence of hazard due to exposure to systemic toxicants, and demonstrates that the vast majority of the ILCR estimate is attributable to external exposure to gamma radiation associated with ^{226}Ra in on-site materials. The risk characterized below for the occupational scenario is designated ILCR_{occ} .

3.1.1.1 Toxicity and Exposure Assessment Integration

The risk model for the occupational scenario, incorporating toxicity and exposure assessment information, is, on a grid-and-job-specific basis:

$$ILCR_{occ,g,j} = \frac{SF_{Ra,occ} \times (EF_{occ} \times ET_{occ}) \times ED_{occ} \times \left[([^{226}Ra]_g \times DRF_j) - [^{226}Ra]_b \right] \times F_{g,j}}{UCF_{t1} \times UCF_{t2}} \times UF_{dre}.$$

Equation 3.1.1.1-1

Each variable and non-variable parameter in the above model is defined in either Subchapter 2.1 or in Section 2.2.1. To derive an estimate of the incremental lifetime cancer rate for a randomly-selected member of the permanent, full-time work force at the plant, $ILCR_{occ}$, each $ILCR_{occ,g,j}$ is sampled randomly in proportion to the grid-and-job-specific weighting factor:

$$WF_{g,j} = P_{w,g} \times P_{g,j}$$

Equation 3.1.1.1-2

where:

$$\sum_g \sum_j WF_{g,j} = 1.00.$$

Equation 3.1.1.1-3

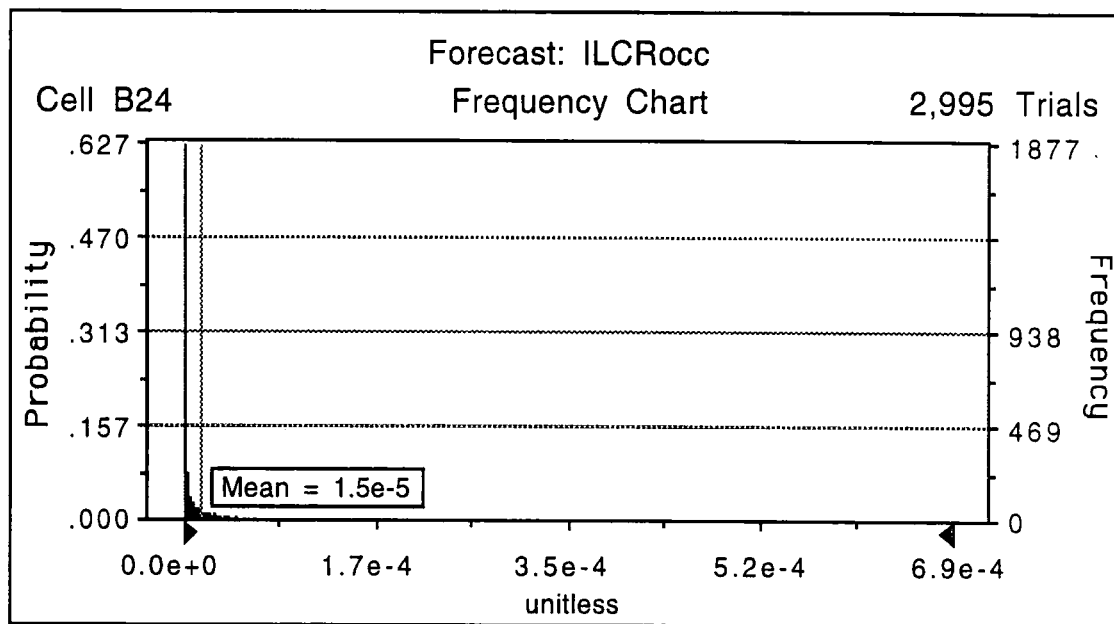
$P_{w,g}$ and $P_{g,j}$ are defined in Section 2.2.1.

The stochastic solution to $ILCR_{occ}$ derives from a 2,995-trial Monte Carlo simulation. Figure 3.1.1.1-1 displays the results graphically; and a complete report of the model run is provided in Appendix F.

Some of the statistics of the $ILCR_{occ}$ distribution, with corresponding subpopulation-specific point estimates from the EPA-10 assessment of current occupational conditions, are:

<u>Statistic</u>	<u>Value</u>	
μ	1.5×10^{-5}	
σ	4×10^{-5}	
P0.50	6×10^{-7}	
P0.90	4×10^{-5}	
P0.94	7×10^{-5}	EPA-10 estimate for a subpopulation of workers exposed to treater dust

Figure 3.1.1.1-1. Plot of the Dependent Variable, $ILCR_{occ}$, in the Risk Model for the Occupational Scenario.



<u>Statistic</u>	<u>Value</u>	
P _{0.95}	8×10^{-5}	
P _{0.98}	1.5×10^{-4}	
P _{0.99}	2×10^{-4}	EPA-10 estimate for a subpopulation of workers exposed to baghouse dust
P _{0.99}	3×10^{-4}	EPA-10 estimate for a subpopulation of workers exposed to nodules
P _{0.998}	4×10^{-4}	EPA-10 estimates for subpopulations of workers exposed to road dust and underflow solids
P _{0.999}	5×10^{-4}	EPA-10 estimate for a subpopulation of workers exposed to slag
C _V	3×10^0	
P _{0.95} /P _{0.050}	5×10^6	

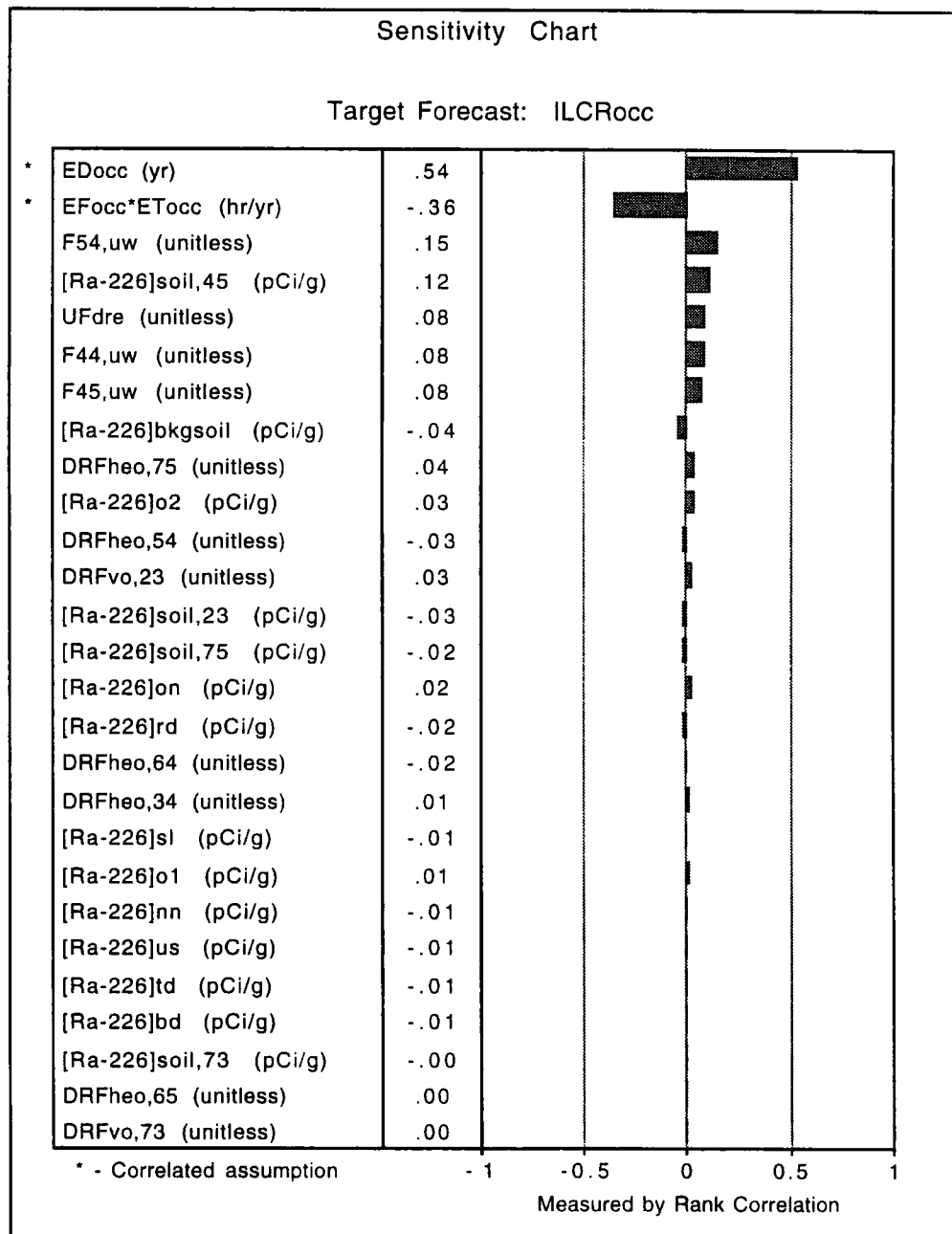
where μ is the mean, σ is the standard deviation, p_q is a specified percentile (*e.g.*, P_{0.50} is the 50th percentile, or median), C_V is the coefficient of variation (*i.e.*, σ/μ), and P_{0.95}/P_{0.050} is the inter-icosatile ratio.

3.1.1.2 Uncertainty Analysis

There is a considerable amount of uncertainty in the estimate of ILCR_{occ}. At 3, C_V is quite high, and the inter-icosatile ratio (which comprises the range within which 90% of the risk estimate lie), at 5,000,000, spans more than six orders of magnitude.

Figure 3.1.1.2-1 contains the results of a rank correlation sensitivity analysis. The sum of the coefficients of determination (*i.e.*, the squared correlation coefficients) is, at 0.49, quite low, indicating that only 49% of the uncertainty can be explained by a linearized view of the model. The predominant reason for this low value is likely due to the manner in which the model evaluates spatial heterogeneity (*i.e.*, the random selection of grid and job categories for each trial is not a linear operation). (As two variables in the model, ED_{occ} and EF_{occ} × ET_{occ}, are correlated, the results of the sensitivity analysis must be interpreted with caution. Correlation can portray a variable to be either more or less important than it really is.)

Figure 3.1.1.2-1. Sensitivity Analysis of the Risk Model for the Occupational Scenario. (Values plotted are rank correlations between the designated independent variable and the dependent variable, $ILCR_{occ}$.)



Of the uncertainty that can be explained by a linearized view of the risk model, ED_{occ} and $EF_{occ} \times ET_{occ}$ appear to be the two variables to which the model and the resulting estimate of $ILCR_{occ}$ are most sensitive. Squaring the r values for ED_{occ} and $EF_{occ} \times ET_{occ}$ indicates that these two variables account for 29% and 13%, respectively, of the overall uncertainty in the model. Combined, they account for 86% of that portion of the uncertainty that is explained by the linearized view of the risk model.

The evaluation of the types of uncertainty, reducible or irreducible, associated with dominant variables in a stochastic model constitutes an informal value-of-information analysis on the benefits of further efforts to refine such variables and, thus, the results of the model. The large degrees of uncertainty in both ED_{occ} and $EF_{occ} \times ET_{occ}$, given that both are defined on the basis of site-specific information, are primarily due to natural variability, rather than lack of knowledge, and are thus, given additional expenditure of project resources, not likely to be appreciably reducible.

A location-specific analysis of the contribution to the overall $ILCR_{occ}$ estimate for an individual selected at random from the permanent, full-time work population, is presented in Figure 3.1.1.2-2. This figure is based on weighted-median estimates of $ILCR_{occ,g}$, the values of which are tabulated in Appendix G. On this basis, nearly 60% of the risk can be attributed to workers assigned to grid 54. More than 80% of the estimated risk is attributable to workers in only three of 23 grids overlaying the plant—54 (the beneficiation area), 34 (the slag pile), and 44 (the furnace area).

Grid 54, where most of the beneficiation activities take place, contains 37% of the plant work force, and grid 44, which includes the furnaces, contains 23%. Of the individuals assigned to grid 54, 95% are assumed to be unshielded (*i.e.*, their jobs do not entail the operation of vehicles or heavy equipment); 100% of those in grid 44 are assumed to be unshielded. Grid 34, which is located on the slag stockpile (see Figure 2.2-2), contains only a small proportion of the work force (1.98%), but the few individuals assigned to this location are assumed to be outdoors, operating heavy equipment, at all times while on the job.

Figure 3.1.1.2-3 presents a job-specific analysis of risk contribution, based on weighted-median $ILCR_{occ,j}$ estimates tabulated in Appendix H. Of the three job categories used in the model—unshielded workers, vehicle operators, and heavy equipment operators—the heavy equipment operator category accounts for the vast majority of the risk, nearly 80%.

Figure 3.1.1.2-2. Pareto Plot of the Location-Specific Contributions to $ILCR_{Ra,occ}$.
(Grid-specific values, which are based on weighted median estimates, are plotted in bar-chart format; cumulative values are plotted in line-chart format.)

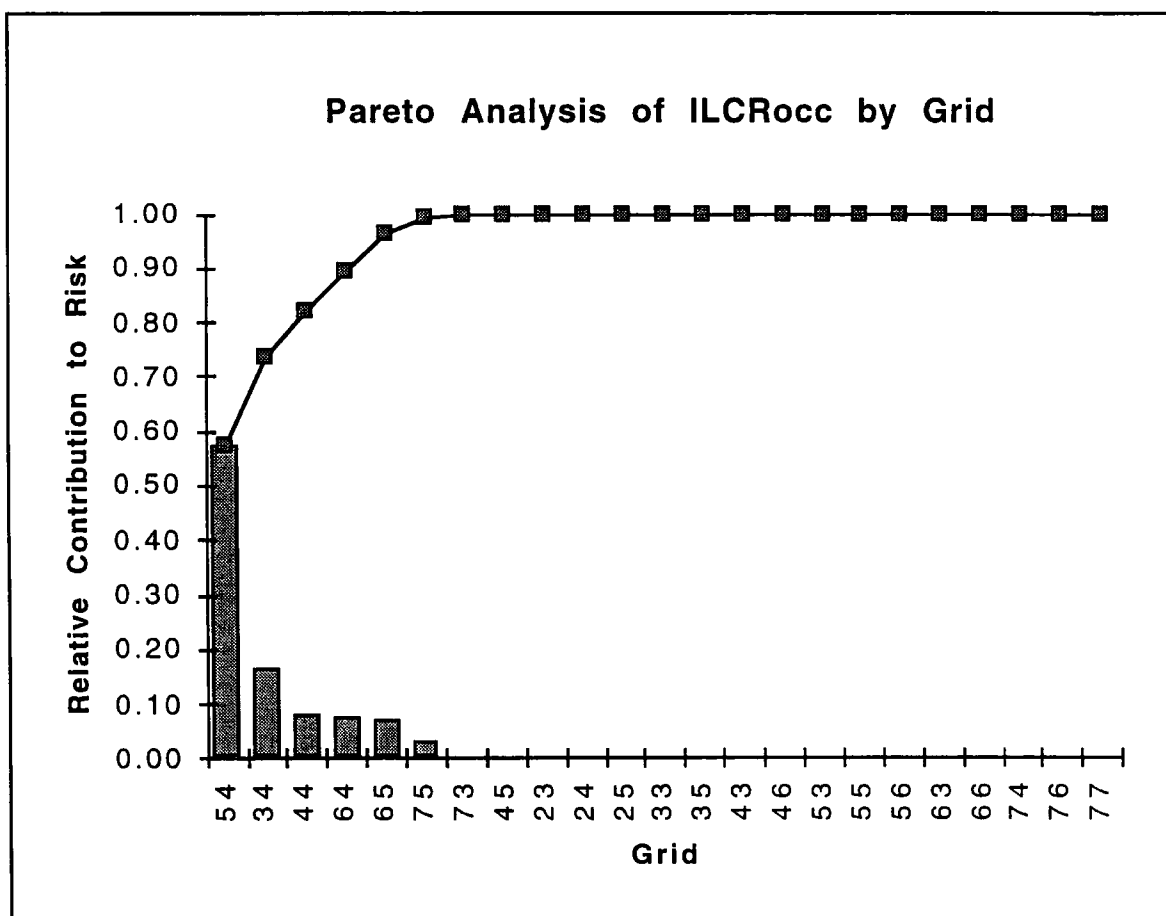
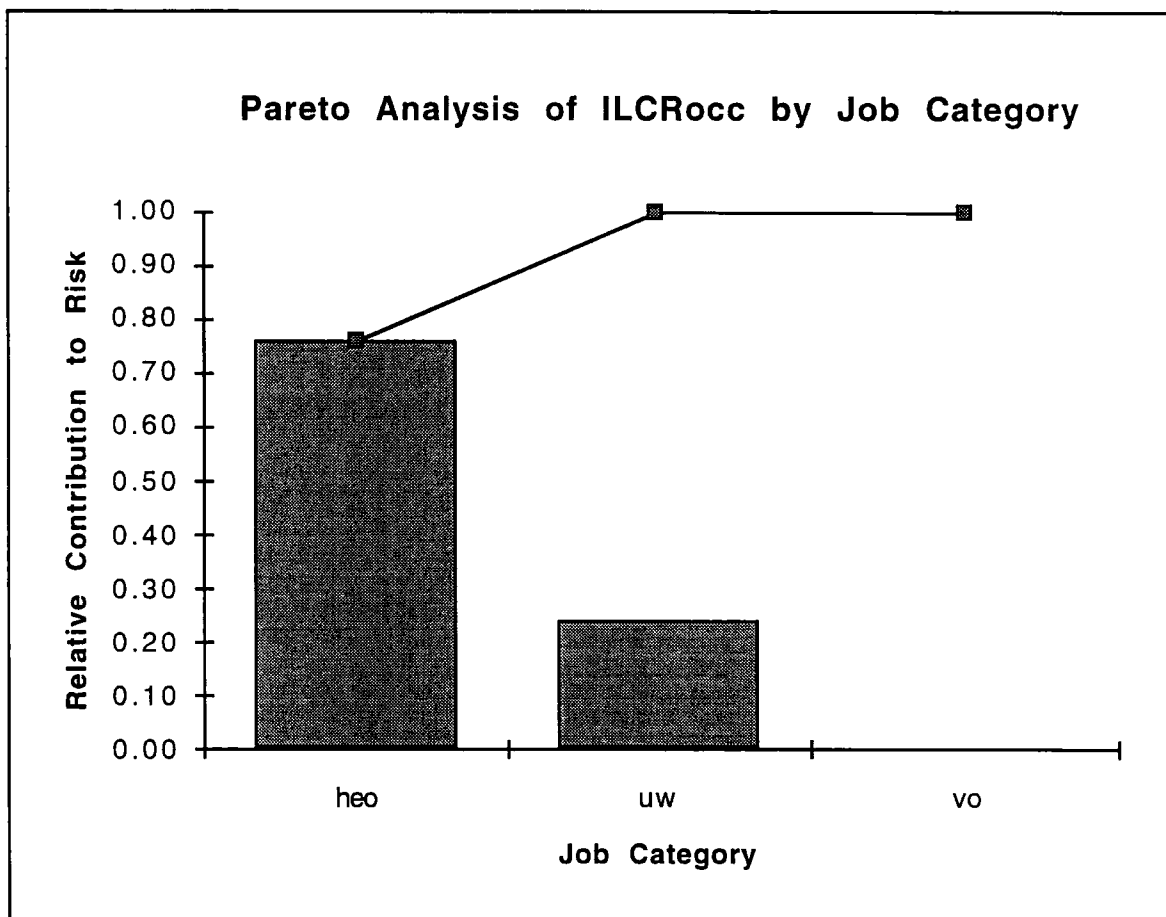


Figure 3.1.1.2-3. Pareto Plot of the Job-Specific Contributions to $ILCR_{occ}$. (Job-specific values, which are based on weighted median estimates, are plotted in bar-chart format; cumulative values are plotted in line-chart format.)



Because only a small proportion of the work force (about 8%) is involved in heavy equipment operations, the magnitude of this contribution is explained by the nature of the job. Heavy equipment operators are responsible for moving materials that are directly derived from phosphate ore, which is enriched in naturally-occurring ^{226}Ra , and are assumed to be outdoors, in their equipment, at all times while on the job.

3.1.2 Risk Description

This section presents an interpretation of the ILCR_{occ} estimate, from both regulatory and pragmatic perspectives, and a comparison to the EPA-10 deterministic risk assessment results for the occupational scenario. A summary of the risk characterization is also provided, along with recommendations for further work.

3.1.2.1 Risk Interpretation

Within a regulatory context, an ILCR of 10^{-6} is defined as a point of departure, or a *de minimus* level of risk, whereas an ILCR of 10^{-4} is defined as the *de maximus* level of risk, a level that, when exceeded, provides a basis for requiring site remediation (40 CFR §300). While EPA may require remediation at risk levels down to 10^{-6} , agency policy is to not remediate sites that do not exceed 10^{-4} unless site-specific reasons justify such action [D.Clay, EPA Office of Solid Waste and Emergency Response (Memorandum to EPA regional hazardous waste division directors) April 22, 1991].

Risk estimates are inherently uncertain because of a high degree of natural variability in environmental and biological systems and a lack of knowledge about many parameters and processes represented in risk models. The wide range of values reported in the stochastic assessment results reflects this uncertainty. Because regulatory agencies have a mandate to protect public health, EPA's final exposure assessment guidelines suggest that risk managers base decisions regarding site remediation on high-end estimates of risk (EPA, 1992).

The final exposure assessment guidelines define a high-end estimate as one that lies within the range of the 90th to 99.9th percentiles, $p_{0.90}$ to $p_{0.999}$. More specifically, the guidelines suggest that the range of reasonable maximum estimates is from $p_{0.90}$ to $p_{0.98}$, and that any estimate exceeding $p_{0.999}$ is to be regarded as a bounding estimate (inconsistencies in terminology leave the validity of estimates in the range of $p_{0.98}$ to $p_{0.999}$

unclear). The guidelines state that it is inappropriate to base the need for a site remedy on a bounding estimate. (A decision for no action is appropriate in instances where a bounding estimate lies below a level of concern; *i.e.*, bounding estimates have screening utility.) The agency's most recent guidance (EPA-8, 1995) indicates that $p_{0.95}$ or $p_{0.90}$ be regarded as reasonable maximum estimates. The various percentiles discussed above are depicted graphically in Figure 3.1.2.1-1.

A fairly broad range of values from the stochastic analysis reflect reasonable maximum estimates of risk. In the case of the occupational scenario, the range is from 2×10^{-5} to 8×10^{-5} . For purposes of discussion, this report focuses on $p_{0.95}$, or $ILCR_{0.95}$, as a representative reasonable maximum estimate. Not only is the 95th percentile in the middle of the range of reasonable maximum estimates, it is also a commonly used statistical decision criterion, and is consistent with EPA-8's recent guidance. For the occupational scenario, $ILCR_{occ,0.95}$ is 8×10^{-5} .

The median estimate of $ILCR_{occ}$ ($ILCR_{occ,0.50}$) of 6×10^{-7} , is below 10^{-6} , while the mean, 1.5×10^{-5} , is an order of magnitude higher than the *de minimus* risk level. While $ILCR_{occ,0.95}$, at 8×10^{-5} , is above the *de minimus* level, it is below the level at which remediation is required.

EPA-10's risk assessment attempts to derive reasonable maximum risk estimates deterministically rather than stochastically (*i.e.*, by representing uncertain model parameters with point estimates rather than with probability distributions). For the occupational scenario, the agency provides risk estimates on a material-specific subpopulation, rather than on a worker-population-specific, basis. The agency's estimates of current risk range from 7×10^{-5} to 5×10^{-4} .

The agency's current risk estimate for treater dust, 7×10^{-5} , lies at $p_{0.94}$; the estimates for baghouse dust and nodules, 2×10^{-4} and 3×10^{-4} , respectively, lie at $p_{0.99}$; the estimate for road dust and underflow solids, 4×10^{-4} , is at $p_{0.998}$, and the estimate for slag, 5×10^{-4} , is at $p_{0.999}$ (see Appendix F). Per agency policy, the treater dust estimate is a reasonable maximum estimate, while the estimates for baghouse dust, nodules, road dust, underflow solids, and slag could be regarded as bounding estimates because they exceed $p_{0.95}$.

Within a context of a bounding estimate perspective, the latter result could be deemed to be invalid for all but screening purposes. However, the EPA-10 deterministic estimates for materials other than treater dust exceed $ILCR_{occ,0.95}$ by only a factor of 3 to 6, roughly a

half order of magnitude. As $ILCR_{occ,0.95}$ and all six of EPA-10's subpopulation estimates round to 10^{-4} , the results of the stochastic and deterministic evaluations of the current occupational exposure conditions can be regarded as identical.

On the assumption that current conditions at the plant provide the best prediction of future conditions, EPA-10's future risk estimates, which range from 1×10^{-3} to 2×10^{-3} (SAIC, 1995), all exceed $p_{0.9997}$ (see Appendix F) and are thus, by policy definition, bounding estimates. The agency's deterministic estimates exceed the $ILCR_{occ,0.95}$ by a factor of 13 to 30, about one to one and one-half orders of magnitude. Thus, from the perspective that future site conditions will not change significantly from those currently in existence, the agency's deterministic results appear to be invalid. However, there is legitimate scenario uncertainty with respect to future exposure conditions.

As stated above, Monsanto's perspective on future occupational conditions is that they will remain largely unchanged from existing conditions. In fact, an argument can be made that this is a conservative assumption. Over the past two decades, Monsanto has made considerable investment in environmental improvements and expects to continue this course of action. EPA-10, on the other hand, has concerns about occupational exposure potentials should Monsanto cease plant operations at some point and another company take over the site. A worst-case evaluation of this perspective is provided in Appendix I.

The worst-case evaluation is designated $ILCR_{focc,34,EPA}$ —EPA-10's perspective on the future occupational subscenario for the slag pile, which is located within grid 34. The model structure is identical to that used for $ILCR_{occ}$, with the exception that only the subpopulation of hypothetical, unshielded slag-pile workers is evaluated rather than the entire population of site workers. This is a worst-case evaluation because slag has the highest concentration of ^{226}Ra (see Appendix E; new nodules have a slightly higher average concentration, but the standard deviation is much narrower). The model structure and input assumptions are documented in Appendix I. All input assumptions are identical to those used in the $ILCR_{occ}$ model with the exception of the following modifications:

- $EF_{occ2} \times ET_{occ2} - \mu_{EF \times ET}$ is increased from 1,900 hr/yr to 2,000 hr/yr, and $\sigma_{EF \times ET}$ is increased from 194 hr/yr to 200 hr/yr (by applying the C_V of the initial distribution to the new distribution) to move the distribution more in line with conventional wisdom of the 2,000-hr work year; the resulting distribution is $\beta(77, 260, 0, 8,766)$ hr/yr.

- ED_{occ2} — A lognormal distribution based on national statistics, $LN(7.4, 11.7)$ yr, is used (see Paragraph 2.2.1.2).
- $P_{w,g}$ — The proportion of the work force assigned to grid 34 is increased from 1.98% to 100% to allow for an evaluation that is focused solely on the subpopulation of workers assigned to the grid.
- $P_{34,j}$ — $P_{34,heo}$ is reduced to 0, and $P_{34,uw}$ is increased from 0 to 1.00 to allow for an evaluation that assumes that all future workers on the slag pile are unshielded.
- $F_{34,uw2}$ — The fraction of outdoor time spent on the job reflects the national average of 0.50 hr per 8-hr work day (EPA, 1990), or, as a fraction, 0.062; the resulting distribution is $\beta(0.93, 14.0, 0, 1.00)$, which assumes bounds of 0 and 1.00 on the basis of physical constraint.

The model output is fully documented in Appendix I. The value of $ILCR_{focc,34,EPA,0.95}$ is 5×10^{-5} , and virtually all of the uncertainty in the model is attributable to three out of the six input variables— $F_{34,uw2}$, ED_{occ2} , and $EF_{occ2 \times ET_{occ2}}$. EPA-10's corresponding point estimate of 2×10^{-3} is in excess of $p_{0.9997}$.

These results confirm that EPA-10's point estimate is a bounding estimate. The close agreement between $ILCR_{focc,34,EPA,0.95}$ and $ILCR_{occ,0.95}$ — 5×10^{-5} vs. 8×10^{-5} —indicates that scenario uncertainty is relatively unimportant for the future occupational conditions. The slightly lower risk estimate for unshielded worker exposures, even on the slag pile, is explained by the Pareto plot in Figure 3.1.1.2-3—heavy equipment operators, who are assumed to be continuously exposed to stockpiled materials, have by far the highest exposures.

As is seen by the above comparisons, deterministic risk estimates are often quantitatively deficient in that they tend to be overly conservative. In addition, they are qualitatively deficient in that they do not comply with PARCC parameter requirements set forth in applicable data quality objectives guidelines (EPA, 1987):

- Precision—uncertainty is not quantified in a deterministic assessment [quantification of uncertainty is also a specific requirement of the final exposure assessment guidelines (EPA, 1992)];
- Accuracy—deterministic risk estimates are intentionally and conservatively biased (without a stochastic assessment for comparison, the degree of conservatism can not be known);
- Representativeness—deterministic risk estimates are often bounding estimates that are not representative of the risks actually experienced by even the relatively highly exposed members of the receptor population; furthermore, a deterministic point estimate has no statistical meaning (*e.g.*, it is neither an average or a specific percentile; it may well correspond to a given percentile, but a stochastic analysis must be performed to determine which one);
- Comparability—deterministic risk estimates are inherently incomparable (*i.e.*, one risk estimate can not be meaningfully compared to another, either from the same site or from a different site); to be comparable, a risk estimate must be tied to a percentile; and,
- Completeness—a deterministic risk estimate is inherently incomplete; it is simply one point from an underlying distribution of an infinite possible set of points.

From a pragmatic perspective, the various levels of risk discussed herein, including the EPA-10's deterministic risk estimates, are not statistically detectable. To demonstrate this fact, the following table shows the size of the human population (one half exposed, the other half an unexposed control) needed to detect a given incremental lifetime cancer rate, assuming a 95% level of certainty (*i.e.*, a Type I, or false positive, error rate of 5%), an 80% level of power (*i.e.*, a Type II, or false negative, error rate of 20%), and a background lifetime cancer risk, per the American Cancer Society, of 3×10^{-1} (*i.e.*, about three in ten North Americans get cancer at some point in their lives):

<u>ILCR Estimate</u>	<u>Required Population Size</u>
10 ⁻⁶ regulatory <i>de minimus</i> level	5×10 ¹² ~1,000× the population of the Earth
1.5×10 ⁻⁵ mean ILCR _{occ}	2×10 ¹⁰ ~4× the population of the Earth
8×10 ⁻⁵ ILCR _{occ,0.95}	8×10 ⁸ ~0.16× the population of the Earth
10 ⁻⁴ regulatory <i>de maximus</i> level	5×10 ⁸ ~2× the population of the United States of America
2×10 ⁻³ EPA-10's highest deterministic estimate	1.3×10 ⁶ ~1.0× the population of the State of Idaho

Another way to put the risk estimate into perspective is to transform the ILCR into an estimate of incremental lifetime lost (ILTL). As mentioned above, about three in ten people, for a wide variety of reasons, will get cancer. The American Cancer Society (1994) reports that there is a 53% survival rate among those who do get cancer (*i.e.*, a 47% mortality rate), and Kathren *et al.* (1993) report that a fatal cancer induced by radiation results, on average, in the loss of 15 years of life (relative to what one could expect if the fatal cancer did not occur). Thus, the estimated lifetime lost due to cancer (LTL) for a person who does not work at Monsanto's Soda Springs Plant is about 2 years:

$$\text{LTL} = 0.3 \times 0.47 \times 15 \text{ yr} \approx 2 \text{ yr}.$$

Equation 3.1.2.1-1

For someone who does work at the plant, the incremental lifetime lost is, using a high-end estimate of ILCR_{occ}, estimated to be about 5 hours:

$$\text{ILTL}_{\text{occ}} = (8 \times 10^{-5}) \times 0.47 \times 15 \text{ yr} \times 365.25 \frac{\text{d}}{\text{yr}} \times 24 \frac{\text{hr}}{\text{d}} \approx 5 \text{ hr}.$$

Equation 3.1.2.1-2

Thus, a permanent, full-time employee at the plant can expect to lose about 2 years and 5 hours of life due to cancer, rather than the 2 years that would be anticipated without working at the plant. (This simple analysis has been conducted deterministically and does not characterize the inherent uncertainty involved in converting an uncertain ILCR estimate

into an ILTL estimate. What is important, however, are the relative units—that the $ILTL_{occ}$ is on the order of hours, not days, weeks, months, or years. A stochastic analysis, not documented here, yielded an $ILTL_{occ,0.95}$ of 3 hr.)

Another way in which to put the occupational risk estimate into perspective is to convert from risk to radiation dose and compare to the standard promulgated and enforced by the United States Occupational Safety and Health Administration (OSHA). The *BEIR V* report estimates the incremental fatal cancer risk as 8×10^{-4} per rem, where a rem is a standard unit of radiation exposure. To adjust this value for protracted and low-dose exposures, it must be divided by an average dose-rate effectiveness factor of 4 to yield $2 \times 10^{-4}/\text{rem}$. As our risk estimate is presented in terms of cancer incidence rate, rather than cancer mortality rate, it must be divided by the mortality rate of 0.47 to yield $4 \times 10^{-4}/\text{rem}$, the desired number for the comparison of interest.

For someone who works at the plant, the incremental occupational radiation exposure or incremental dose, ID, using a high-end estimate of $ILCR_{occ}$, is estimated to be about 0.2 rem:

$$ID = \frac{8 \times 10^{-5}}{4 \times 10^{-4} \frac{\text{rem}}{\text{rem}}} \approx 0.2 \frac{\text{rem}}{\text{rem}}.$$

Equation 3.1.2.1-3

OSHA's standard is 5 rem/yr (29 CFR 1910.96). Thus, a conservative estimate of the incremental dose to a plant worker, *for the duration of employment at the plant*, is a mere 4% of OSHA's *annual* standard.

3.1.2.2 Risk Summary

The stochastic assessment of environmental exposure risk related to occupational activities at the Monsanto Soda Springs Plant predicts an incremental lifetime cancer incidence rate for a permanent, full-time worker that is 95% likely to be less than 8×10^{-5} (0.00008, or eight in one-hundred-thousand). This is the estimate of risk that is in excess of the North American background cancer incidence rate of 3×10^{-1} (0.3, or three in ten). In other words, a conservative estimate of the overall cancer incidence rate for a randomly-selected plant worker is 0.30008; whereas, an unbiased estimate of the overall cancer incidence rate for a randomly-selected individual from the general North American population is 0.3.

From a regulatory perspective, this level of incremental risk generally requires no need for remedial action. The risk estimate also indicates an absence of any imminent and substantial endangerment to the work force from environmental exposures.

The uncertainty analysis shows that EPA-10's deterministic risk estimates for future conditions at the plant are overly conservative bounding estimates. Sensitivity analysis shows that the stochastic risk model is most sensitive to assumed distributional estimates of exposure duration and the number of hours worked per year. An informal value-of-information analysis, however, concludes that it would likely not be productive to attempt to refine these variables and, consequently, the model's prediction, because the uncertainty embodied within the distributions is mostly due to natural variability rather than lack of knowledge.

An evaluation of scenario uncertainty with respect to future occupational exposure conditions proves that the occupational model presented is robust and is insensitive to assumptions about future exposure factors. It also demonstrates the validity of assuming that future site conditions are conservatively approximated by modeling current conditions.

More effort could be expended to refine grid-specific and job-specific work force assignments, which are defined deterministically in the existing model. These types of refinements, however, would not be expected to result in a substantial modification of the model prediction. Time stepping the model (evaluating risk over smaller increments of time, *e.g.*, year by year) could be done, and such a model would result in a narrower risk output distribution—low-end risk estimates will increase and high-end risk estimates will decrease. A time-stepped model is more realistic because a worker's exposure is not likely to be constant throughout his entire duration of employment.

Contribution analysis indicates that the vast majority of the risk estimate is attributable to a few locations (13% of the grids—the beneficiation area, grid 54; the furnace area, grid 44; and, the slag stockpile, grid 34—account for more than 80% of the sum of the grid-specific weighted median risk estimates). A job-specific contribution analysis indicates that nearly 80% of the sum of the weighted median risks can be traced to those individuals who operate heavy equipment.

3.2 Residential Scenario

The risk characterization phase for the current residential subscenario is documented in Section 3.2.1; for the future residential subscenario, risk characterization documentation is provided in Section 3.2.2.

3.2.1 Current Residential Subscenario

Risk estimation results for the current residential subscenario at Monsanto's Soda Springs Plant are presented in Subsection 3.2.1.1. The risks are discussed in Subsection 3.2.1.2.

3.2.1.1 Risk Estimation

SAIC (1995) documents an absence of hazard due to exposure to systemic toxicants for current residents in the near vicinity of the plant, and demonstrates that ingestion of As in soil is a dominant constituent-pathway element. The risk characterized below is designated $ILCR_{\text{cres}}$ to denote the current residential subscenario.

3.2.1.1.1 Toxicity and Exposure Assessment Integration. The risk model for the current residential subscenario, incorporating toxicity and exposure assessment information, is, on a grid-specific basis:

$$ILCR_{\text{cres},g} = \frac{SF_{\text{As}} \times \text{Ing}R_{\text{s/d}} \times EF_{\text{res}} \times ED_{\text{res}} \times ([\text{As}]_g - [\text{As}]_b) \times BF_{\text{s,As}} \times F_s \times F_l \times UCF_m}{BW \times BF_{\text{w,As}} \times AT \times UCF_{t2}}$$

Equation 3.2.1.1.1-1

Each variable and non-variable parameter in the above model is defined in either Subchapter 2.1 or in Subsection 2.2.2.1. To derive an estimate of the incremental lifetime cancer rate for a randomly-selected resident in the near vicinity of the plant, $ILCR_{\text{cres}}$, each $ILCR_{\text{cres},g}$ is sampled randomly in proportion to $P_{r,g}$, the grid-specific proportion of existing residences in the near vicinity of the plant. $P_{r,g}$ values for the current residential subscenario are defined in Subsection 2.2.2.1.

The stochastic solution to $ILCR_{\text{cres}}$ derives from a 2,995-trial Monte Carlo.

Figure 3.2.1.1.1-1 displays the results graphically; a complete report of the model run is provided in Appendix L.

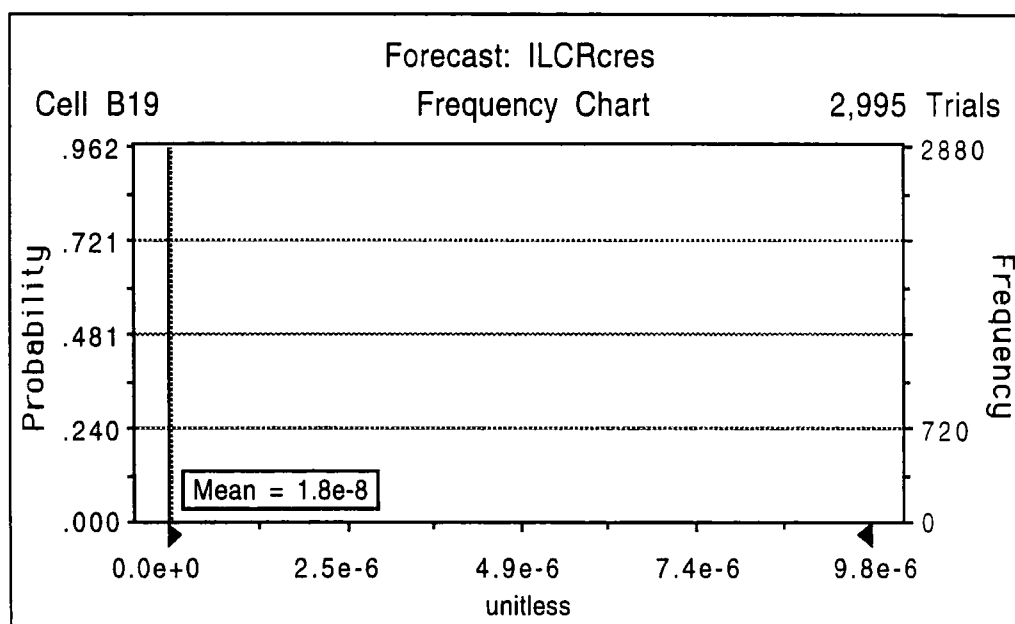
Some of the statistics of the $ILCR_{\text{cres}}$ distribution, with the corresponding point estimate for the western location from the EPA-10 assessment of current residential conditions, are:

<u>Statistic</u>	<u>Value</u>	
μ	1.8×10^{-8}	
σ	2×10^{-7}	
P0.50	0	EPA-10 estimate for the subpopulation of residents to the west of the plant
P0.90	5×10^{-9}	
P0.95	2×10^{-8}	
P0.98	1.1×10^{-7}	
P0.99	3×10^{-7}	
P0.999	3×10^{-6}	
C_V	1.3×10^1	
P0.95/P0.050	∞	

The inter-icosatile range is infinite because $p_{0.050}$ is 0. Even the median, or $p_{0.50}$, is 0. The high proportion of 0 values in the distribution is a result of $[As]_g$ distributions being virtually identical to that representing $[As]_b$. (When one distribution is subtracted from an identical distribution, about one-half of the values in the resulting distribution are negative. All three human health risk models for the Monsanto plant, however, truncate negative values at 0. Appendix L indicates that roughly two-thirds of the risk estimates for the current residential scenario are 0. This is because background samples were obtained from a wide area, and the resulting distribution for $[As]_b$ is thus broader than those for $[As]_g$.)

In specific regard to the current residential subscenario, the form of $ILCR_{\text{cres}}$, is determined by the lack of elevated levels of As in soil, relative to distribution of As in background soil, in the grids where residences currently exist. This situation is demonstrated in Figure 2.2-1, which shows that the currently developed residential areas to the west of the plant are well outside the area of elevated levels of As.

Figure 3.2.1.1.1-1. Plot of the Dependent Variable, $ILCR_{\text{cres}}$, in the Risk Model for the Current Residential Subscenario.



3.2.1.1.2 Uncertainty Analysis. Uncertainty in the estimate of $ILCR_{\text{cres}}$, based on a C_V of 13, can be regarded as very high. The high proportion of 0 values and an understanding of the model structure, however, lead to the conclusion that the model is simply generating background noise. This conclusion provides a high degree of certainty in the virtual absence of any risk to existing residents that can be attributable to past and present plant operations.

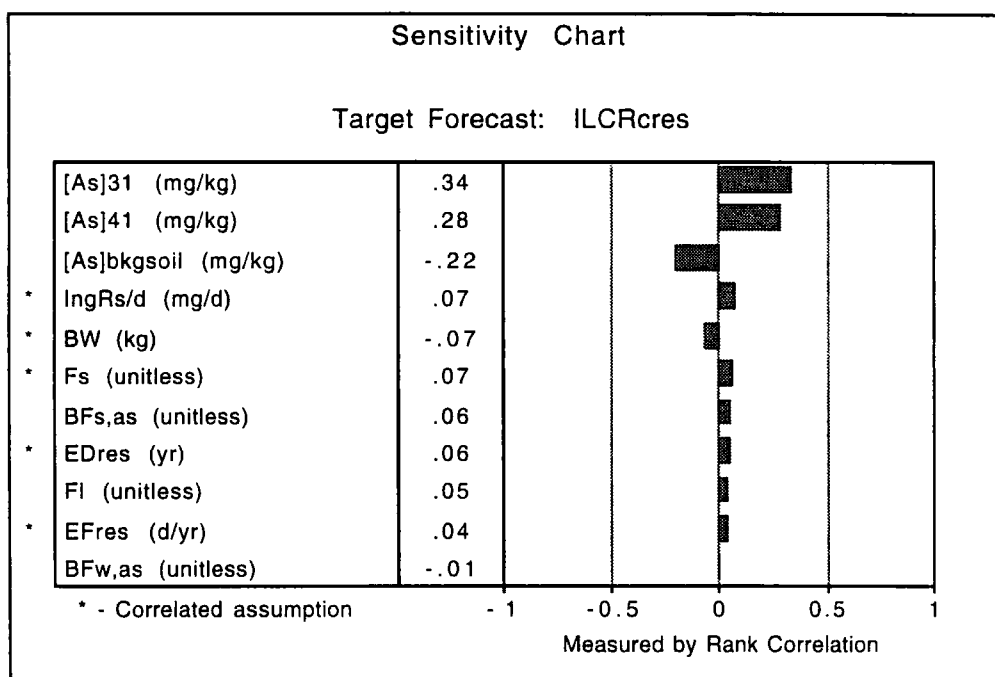
Figure 3.2.1.1.2-1 presents the results of a rank correlation sensitivity analysis for the current residential subscenario. The sum of the coefficients of determination, at a low value of 0.27, indicates that only about one-quarter of the uncertainty in the estimate of $ILCR_{\text{cres}}$ can be explained by a linearized view of the model. (Because several of the input variables are correlated, the results of the sensitivity analysis must be interpreted with caution; see Subsection 3.1.1.2.) The conclusion that background noise is being generated is supported by this sensitivity analysis. The three variables the model is most sensitive to are those representing the As concentrations in the soil of the two grids that currently contain residences, and in background soil.

A grid-specific contribution analysis of $ILCR_{\text{cres}}$ indicates that the overall risk estimate, on a weighted-median basis, is equally partitioned between grids 31 and 41. The values of $ILCR_{\text{cres},g,0.50}$ are presented in Appendix M.

For purposes of stochastic analysis, all scenarios and subscenarios have been simplified to one-constituent, one-pathway models. In the occupational scenario, external exposure to ^{226}Ra -derived gamma radiation was shown to account for at least 90% of EPA-10's multiple-constituent, multiple-pathway deterministic risk estimate. In the future residential subscenario, such exposure was shown to account for at least 90% of the overall risk estimated deterministically by the agency for three out of four locations evaluated (the three with the highest estimated risks; Be ingestion is the most important at the fourth location, which has a deterministic risk estimate that is three orders of magnitude lower than the highest estimate; SAIC, 1995). Thus, it is reasonable to view the occupational scenario and future residential subscenario in terms of one-constituent, one-pathway models.

In the current residential subscenario, ingestion of As is the most important constituent-pathway element in EPA-10's deterministic risk estimate at one of three locations evaluated (the location with the largest risk estimate); it accounts for about 50% of an estimated $ILCR$ of 2×10^{-5} . Ingestion of Be is important at the other two locations, including the western

Figure 3.2.1.1.2-1. Sensitivity Analysis of the Risk Model for the Current Residential Subscenario. (Values plotted are rank correlations between the designated independent variable and the dependent variable, $ILCR_{cres}$.)



location, the only location where people currently live. Ingestion of Be at this location accounts for about 30% of the EPA-10 overall ILCR; whereas, ingestion of As contributes 0%. Thus, the validity of a one-constituent, one-pathway model to represent the current residential subscenario is questionable. However, the stochastic results of the As ingestion model presented here do substantiate the results of the deterministic model in pointing out that any risk to current residents is very low.

To evaluate the effect of focusing on only one contaminant-pathway element when that element does not dominate the deterministic risk estimate, an assessment of a Be ingestion version of the current residential subscenario, $ILCR_{\text{cres,be}}$, is presented in Appendix N. The $ILCR_{\text{cres,be}}$ model is identical to $ILCR_{\text{cres}}$, except that $[Be]_g$ concentrations, derived from kriging as explained in Appendix D, replace $[As]_g$, $[Be]_b$ replaces $[As]_b$, and $BF_{w,Be}$ and $BF_{s,Be}$ replace $BF_{w,As}$ and $BF_{s,As}$, respectively. The inputs and output for $ILCR_{\text{cres,be}}$ are documented in Appendix N.

The value of $ILCR_{\text{cres,be},0.95}$ is 4×10^{-8} . This value is about two orders of magnitude lower than EPA-10's corresponding point estimate of 2×10^{-6} , which lies on $p_{0.995}$. Despite the discrepancy, both estimates are well below the remedial action threshold, and both corroborate the conclusions derived from $ILCR_{\text{cres}}$. The insignificance of the high-end risk estimate for Be ingestion is consistent with the western residences being well outside the zone of soil affected by elevated Be concentrations (see Figure 2.2-1).

3.2.1.2 Risk Description

This subsection presents an interpretation of the $ILCR_{\text{cres}}$ estimate, from both regulatory and pragmatic perspectives. A comparison of the estimate to those produced by EPA-10 in their deterministic risk assessment is also presented in Paragraph 3.2.1.2.1. A summary of the risk characterization and recommendations regarding the need for further work on the current residential subscenario are provided in Paragraph 3.2.1.2.2.

3.2.1.2.1 Risk Interpretation. The estimate of $ILCR_{\text{cres},0.95}$ is 2×10^{-8} , which is about two orders of magnitude below the *de minimus* level of 10^{-6} (see Subsection 3.1.2.1).

Therefore, there is clearly, by regulatory definition, no threat to the health of nearby residents. EPA-10's deterministic estimates range from 6×10^{-6} to 2×10^{-5} (SAIC, 1995). Because the deterministic estimates do not exceed 10^{-4} , they support the conclusion about the absence of any health threat to existing residents.

To place an ILCR estimate of 2×10^{-8} into perspective, the associated incremental lifetime lost for one of the nearby residents is estimated, using Equation 3.1.2.1-2, to be 4 seconds (relative to a background value of 2 years). This estimate is conservative because skin cancer, a highly curable form of cancer, is the prevalent form associated with As ingestion (*i.e.*, the mortality rate is less than the 47% assumed). In addition, the lifetime lost per fatal cancer estimate of 15 years is derived from information on radiologically-induced cancers; the estimate for skin cancer is likely to be much lower.

3.2.1.2.2 Risk Summary. The stochastic assessment of environmental exposure risk related to living near Monsanto's Soda Springs Plant predicts an incremental lifetime cancer incidence rate for a current resident that is 95% likely to be less than 2×10^{-8} (0.00000002, or two in one-hundred-million). From a regulatory perspective, this level of risk indicates no need for further action.

Given that the level of predicted risk to current residents is so low, and that Be ingestion results are similar to those for As ingestion, there is really no need for model refinement.

3.2.2 Future Residential Subscenario

Risk estimation results for the future residential subscenario at the Monsanto Soda Springs Plant are presented in Subsection 3.2.2.1. These risks are discussed in Subsection 3.2.2.2.

3.2.2.1 Risk Estimation

SAIC (1995) documents an absence of hazard due to exposure to systemic toxicants for future residents in the near vicinity of the plant, with the exception of ingestion of ground water. A small portion of the aquifer to the south-southeast of the plant has been affected by past plant operations and contains elevated levels of F and Se.

EPA-10 estimates a hazard quotient (HQ) of 2 due to potential ingestion of F in this water, and an HQ of 1.4 due to the potential ingestion of Se. The likelihood of ground water in this area being used for drinking water is very low, given the proximity of the City of Soda Springs and the abundance of the city's water supply. A more realistic assessment of risk associated with future ground-water consumption from the affected portion of the aquifer would incorporate a likelihood estimate for the future use of the affected ground water. A

likelihood as high as 50% would drop the EPA-10 HQ estimates to or below 1.0, the remedial action threshold for non-carcinogens (40 CFR §300).

CERCLA requires that relevant and appropriate environmental regulatory standards, such as primary maximum contaminant levels (1° MCLs; 40 CFR §141) promulgated pursuant to the Safe Drinking Water Act (42 USC §300f *et seq.*), be considered in the determination of the need for site remediation. Both F and Se are either known or predicted to exceed their respective 1° MCLs in that portion of the aquifer next to and south-southeast of the plant. Given the obvious need to evaluate actions to prevent exposure to elevated levels of F and Se in the ground water, no attempt has been made in this assessment to generate more realistic HQ estimates through the use of stochastic modeling.

The EPA-10 deterministic assessment demonstrates that external exposure to ^{226}Ra -associated gamma radiation accounts for virtually all of their ILCR estimates for three out of the four locations evaluated. Ingestion of Be in soil is the most significant constituent-pathway element at the fourth location, southern II. Figure 2.2-1, however, indicates that elevated Be concentrations do not extend south to grid 5, the one grid that corresponds best with EPA-10's southern II location. The evaluation of $\text{ILCR}_{\text{cres,be}}$, presented in Paragraph 3.2.1.1.2, indicates that high-end cancer risk estimates are insignificant when constituent levels are not significantly elevated above background. Thus, it is appropriate to focus the future residential subscenario to a single contaminant-pathway model. The risk characterized below is designated $\text{ILCR}_{\text{fres}}$ to denote the future residential subscenario.

3.2.2.1.1 Toxicity and Exposure Assessment Integration. The risk model for the future residential subscenario is, as is the case for the previously discussed scenarios, grid-specific:

$$\text{ILCR}_{\text{fres,g}} = \frac{\text{SF}_{\text{Ra,res}} \times \text{EF}_{\text{res}} \times \text{ED}_{\text{res}} \times \left[\left([^{226}\text{Ra}]_{\text{g}} \times \text{TSGF} \times \text{DRF} \right) - [^{226}\text{Ra}]_{\text{b}} \right] \times F_0 \times F_1}{\text{UCF}_{\text{t2}}} \times \text{UF}_{\text{dre}}.$$

Equation 3.2.2.1.1-1

Each variable and non-variable parameter in the above model is defined in either Subchapter 2.1 or in Subsection 2.2.2.2. To derive an estimate of the incremental lifetime cancer rate for a randomly-selected future resident in the near vicinity of the plant, $\text{ILCR}_{\text{fres}}$, each $\text{ILCR}_{\text{fres,g}}$ is sampled randomly in proportion to $P_{\text{r,g}}$, the grid-specific

proportion of future residents in the near vicinity of the plant. $P_{r,g}$ values for the future residential subscenario are defined in Subsection 2.2.2.2.

The stochastic solution to $ILCR_{fres}$ derives from a 2,995-trial Monte Carlo simulation. Figure 3.2.2.1.1-1 displays the results graphically; a complete report of the model run is provided in Appendix Q.

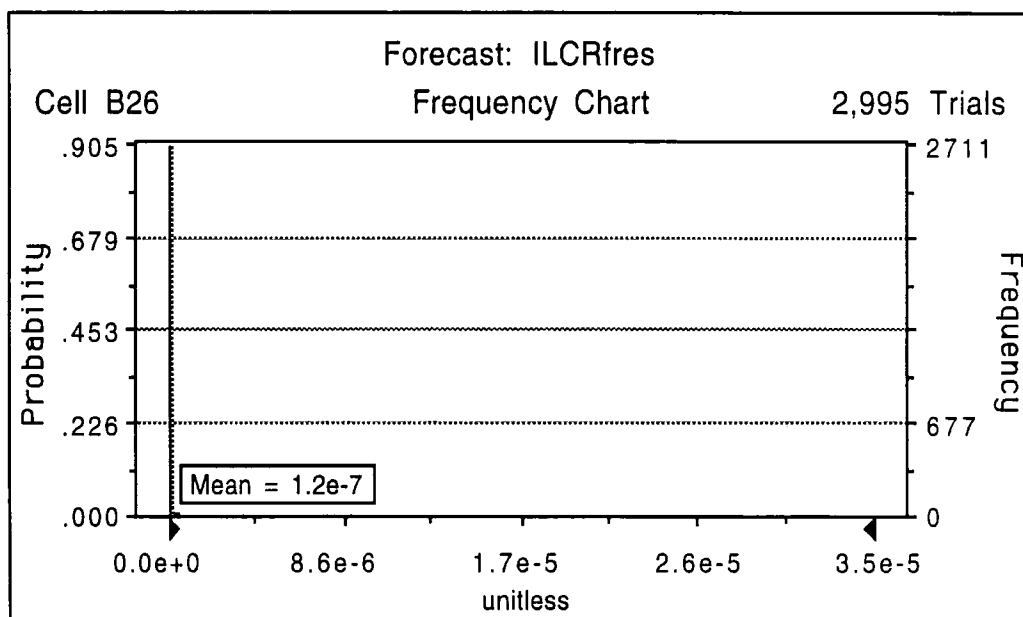
Some of the statistics of the $ILCR_{fres}$ distribution, with the corresponding point estimates for the four locations from the EPA-10 assessment of future residential conditions, are:

<u>Statistic</u>	<u>Value</u>	
μ	1.2×10^{-7}	
σ	1.0×10^{-6}	
P0.50	0	EPA-10 estimate the southern II residential subpopulation
P0.90	1.0×10^{-7}	
P0.95	3×10^{-7}	
P0.98	1.1×10^{-6}	
P0.99	2×10^{-6}	
P0.999	1.6×10^{-5}	
> P0.9997	1×10^{-4}	EPA-10 estimate for the northern II residential subpopulation
> P0.9997	2×10^{-3}	EPA-10 estimate for the northern I and southern I residential subpopulations
C_V	8×10^0	
P0.95/P0.050	∞	

The 0 median and the infinite inter-icosatile range are a result of $[^{226}\text{Ra}]_g$ values generally being within the range of $[^{226}\text{Ra}]_b$ (see Paragraph 3.2.1.1.1 for a similar discussion related to $[\text{As}]_g$). There is a lack of elevated ^{226}Ra in soil, relative to the amount found in background soil, in the grids where most of the future residents are predicted to live.

The model conservatively assumes that people will live in all grids, except those that are entirely classified as non-residential due to industrial/commercial zoning, Monsanto ownership, or the presence of park land. The relative proportion of future residents in each potentially residential grid is estimated on the basis of current use, ownership, and zoning

Figure 3.2.2.1.1-1. Plot of the Dependent Variable, $ILCR_{fres}$, in the Risk Model for the Future Residential Subscenario.



classification. Table 2.2.2.2.6-1 indicates that two-thirds of the future population of nearby residents are expected to inhabit grids 5 and 6 (*i.e.*, EPA-10's southern II location).

3.2.2.1.2 Uncertainty Analysis. Uncertainty in the estimate of $ILCR_{fres}$, based on a C_V of 8, can be regarded as very high. The high proportion of 0 values, about two-thirds (see Appendix Q), and an understanding of the model structure, however, lead to the conclusion that the model is, to a large extent, generating background noise. This conclusion provides a high degree of certainty in the low level of risk predicted for future residents, which is conservatively predicted to be only 3×10^{-7} at $ILCR_{fres,0.95}$.

Figure 3.2.2.1.2-1 presents the results of a rank correlation sensitivity analysis for the future residential subscenario. The sum of the coefficients of determination is only 0.168; therefore, a linearized view of the model does not account for about five-sixths of the uncertainty. (Several input variables are correlated; thus, the results of this analysis must be interpreted with caution; see Subsection 3.1.1.2.)

Almost two-thirds of the small portion of uncertainty that is explained by a linearized perspective of the model can be attributed to three concentration variables— $[^{226}Ra]_b$, $[^{226}Ra]_6$, and $[^{226}Ra]_5$ —and the most dominant of these is the background concentration variable. Thus, the sensitivity analysis supports the conclusion that the $ILCR_{fres}$ model is demonstrating that the degree of risk is mostly within the range of background noise.

A grid-specific analysis of $ILCR_{fres}$, displayed in Figure 3.2.2.1.2-2, indicates that the overall risk estimate, based on the sum of the weighted $ILCR_{fres,0.50}$ s for each grid, is dominated by grids adjacent to the north and west plant fence lines. This, not surprisingly, is the area of residential development potential (low though it may be) that contains the highest ^{226}Ra concentrations in soil (see Figure 2.2-1). As shown in Figure 3.2.2.1.2-2, the ten top risk-contributing grids, all of which are located to the north or west of the plant, account for 80% of the sum of the weighted-median risks. These ten grids represent only about 14% of the 69 grids having residential development potential.

Legitimate uncertainty exists regarding where residential development will occur within the near vicinity of the plant. Monsanto's perspective is that no development will occur in the immediate vicinity (*i.e.*, adjacent to the plant fence line). Thus, $ILCR_{fres}$ is very conservative from this perspective because adjacent development is allowed in the model. EPA-10 has valid concerns about using current land use and zoning to predict the relative

Figure 3.2.2.1.2-1. Sensitivity Analysis of the Risk Model for the Future Residential Subscenario. (Values plotted are rank correlations between the designated independent variable and the dependent variable, $ILCR_{fres}$. Given the large size of the model, only the ten variables the model is most sensitive to are displayed.)

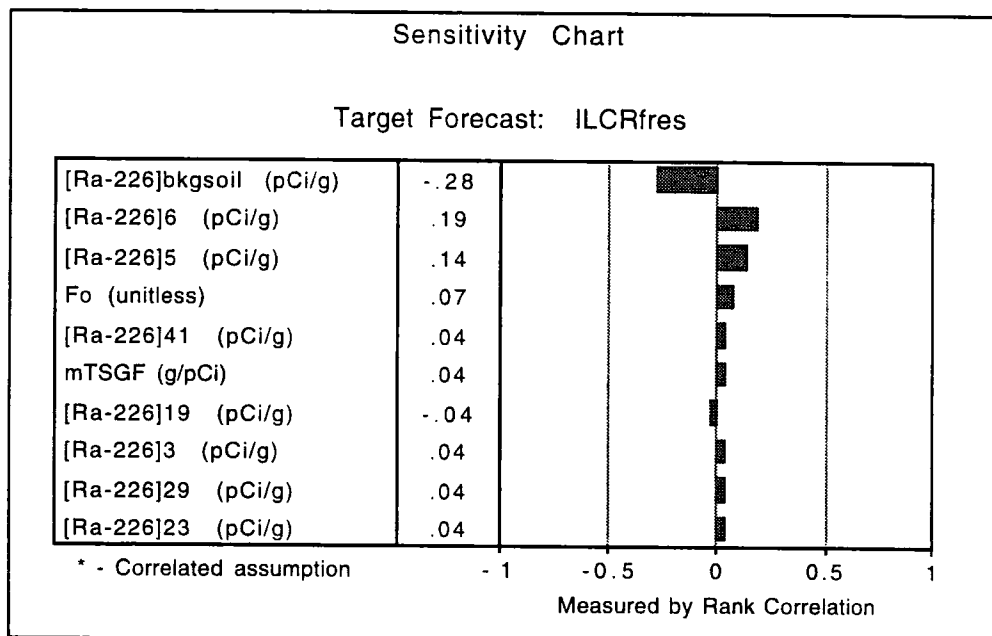
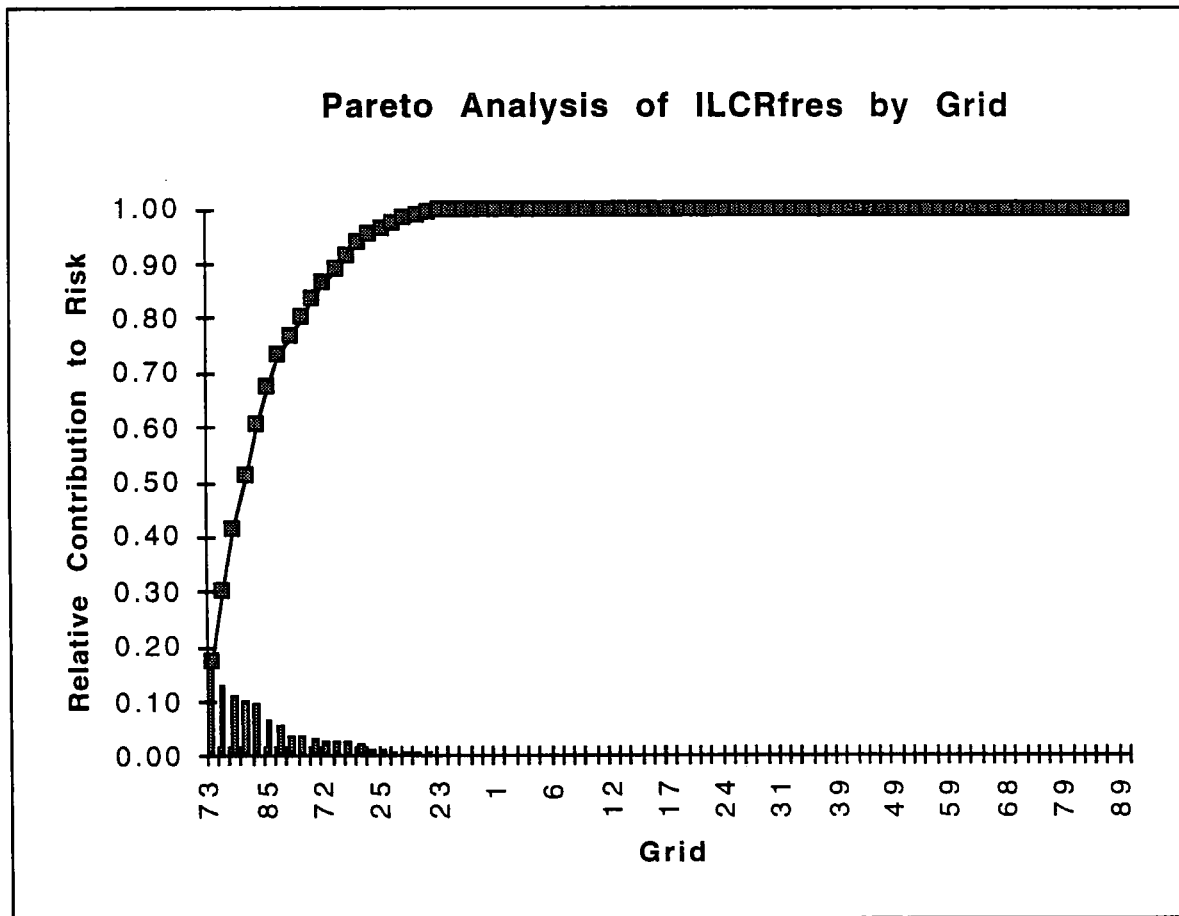


Figure 3.2.2.1.2-2. Pareto Plot of the Location-Specific Contributions to $ILCR_{fres}$.

(Grid-specific values, which are based on median estimates, are plotted in bar-chart format; cumulative values are plotted in line-chart format. Due to space limitations, all grids are plotted, but not all are labeled. The first ten grids, which account for 80% of the risk, are, in order of decreasing importance, 73, 74, 75, 63, 84, 85, 83, 43, and 53. Specific values for each grid are tabulated in Appendix R.)



density of the future, nearby residential population when such use and zoning do not specifically preclude residential development. To evaluate this uncertainty, an alternative version of the future residential subscenario, $ILCR_{fres,EPA}$, was developed.

$ILCR_{fres,EPA}$ is identical to $ILCR_{fres}$, with the exception of the values for $P_{r,g}$, the relative proportion of residents inhabiting grid g at some future point. $P_{r,g}$ values were recalculated assuming uniform relative density of future inhabitants on a quarter-grid level of resolution. The alternative values are shown on the spreadsheet presented in Appendix S. Appendix S also contains complete documentation of the $ILCR_{fres,EPA}$ inputs and output.

A 2,995-trial Monte Carlo simulation generates an $ILCR_{fres,EPA,0.95}$ value of 1.0×10^{-6} . This estimate is only about one-half order of magnitude higher than that of 3×10^{-7} for $ILCR_{fres,0.95}$. Thus, these two results are quite similar. The sensitivity analysis shows that $[^{226}Ra]_b$ accounts for most of the linearly explainable uncertainty in $ILCR_{fres,EPA}$. This demonstrates that $ILCR_{fres,EPA}$, like $ILCR_{fres}$, is to a large extent merely characterizing environmental background noise.

Appendix T provides weighted median $ILCR_{fres,EPA}$ estimate for each grid. The top ten risk-contributing grids within EPA-10's perspective are 73, 74, 75, 63, 84, 85, 83, 53, and 35. These ten grids account for 79% of the sum of the medians, and nine out of the ten are within the top ten in the $ILCR_{fres}$ model that portrays Monsanto's perspective. These results indicate that the degree of uncertainty about the relative spatial density of future residential development in the near vicinity of the plant is minor.

To evaluate uncertainty in defining the future exposed population of interest for this subscenario, a worst-case model, $ILCR_{fres,74}$, was developed. This model evaluates only the subpopulation of residents that might inhabit the northern half of grid 74, the grid on the north plant fence line that contains the highest ^{226}Ra soil concentrations (see Appendix O). Thus, $P_{r,74}$ is increased to 1.00, and all other grids are ignored; all other aspects of the model are identical to $ILCR_{fres}$ and $ILCR_{fres,EPA}$. All inputs and the output of $ILCR_{fres,74}$ are fully documented in Appendix U.

The estimate of $ILCR_{fres,74,0.95}$ generated by a 2,995-trial Monte Carlo simulation is 5×10^{-6} , which is about one order of magnitude higher than $ILCR_{fres,0.95}$ (3×10^{-7}) and one-half order of magnitude higher than $ILCR_{fres,EPA}$ (1.0×10^{-6}). For their northern I location, which corresponds to grid 74, EPA-10's point estimate of 2×10^{-3} is clearly shown to be a

bounding estimate. These two estimates provide for a direct comparison between the stochastic and deterministic assessments. The input assumptions for the two subpopulation models are identical, except that variables are represented as probability distributions in the stochastic version whereas they are represented as conservative point estimates in the deterministic version. The probability distributions used in the stochastic version, however, in all cases encompass their corresponding deterministic value.

The sensitivity analysis for $ILCR_{fres,74}$ shows that the vast majority of uncertainty in the model, 85%, can be explained by a linearized view of the model. Eighty percent of this explainable uncertainty is attributable to three variables— ED_{res} , F_o , and F_l , which are respectively the residential exposure duration, the fraction of time spent outdoors, and the fraction of time spent locally. This sensitivity analysis is quite different from those for $ILCR_{fres}$ and $ILCR_{fres,EPA}$. The difference is attributable to the presence of discernably elevated levels of ^{226}Ra in the soil of grid 74 relative to background.

3.2.2.2 Risk Description

This subsection presents an interpretation of the $ILCR_{fres}$ estimate, from both regulatory and pragmatic perspectives. A comparison of the estimate to those generated by EPA-10's deterministic assessment is also presented in Paragraph 3.2.2.2.1. A summary of the risk characterization and recommendations regarding the need for further work on the future residential subscenario are provided in Paragraph 3.2.2.2.2.

3.2.2.2.1 Risk Interpretation. The estimate of $ILCR_{fres,0.95}$ is 3×10^{-7} , which is well below the *de minimus* level of 10^{-6} . Therefore, there is no threat to the health of future nearby residents. EPA-10's deterministic risk estimates range from 0 to 2×10^{-3} (SAIC, 1995). The highest of EPA-10's estimates exceeds $ILCR_{fres,0.95}$ by a factor of 6,000. With the exception of the unaffected southern II location, the remaining three of the agency's point estimates exceed $p_{0.9997}$, and are thus bounding estimates (see Appendix Q). Thus, per EPA (1992), they are overly conservative and not valid for the purpose of requiring remediation.

This interpretation is confirmed through the evaluation of alternative models to analyze uncertainties regarding future residential development spatial patterns and in the definition of the affected population. The $ILCR_{fres,EPA,0.95}$ value of 1.0×10^{-6} confirms the low magnitude of the future residential risk estimate and the relative insensitivity of the model to

spatial development assumptions. The $ILCR_{fres,EPA}$ analysis also confirms that the EPA-10 point estimates are overly conservative. The $ILCR_{fres,74,0.95}$ of 5×10^{-6} demonstrates that even the most affected subpopulation that could ever exist on the north fence line would experience risks far below the remedial action threshold. The $ILCR_{fres,74}$ analysis further confirms the bounding nature of EPA-10's point estimates.

An $ILCR$ estimate of 3×10^{-7} can be put into perspective by converting it to an estimate of incremental lifetime lost, using Equation 3.1.2.1-2. The resulting $ILTL_{fres}$ estimate is about 70 seconds (relative to a background value of 2 years).

3.2.2.2.2 Risk Summary. The stochastic assessment of environmental exposure risk related to living near the Monsanto Plant predicts an incremental lifetime cancer incidence rate for a future resident that is 95% likely to be less than 3×10^{-7} (0.0000003, or three in ten-million). From a regulatory perspective, this level of risk indicates no need for further action.

Given the low risk prediction, there is no need for model refinement.

Chapter 4



MONTGOMERY WATSON

4 Summary and Conclusions

The deterministic assessment (SAIC, 1995) concludes that there are no human health problems at Monsanto's Soda Springs Plant that are associated with threats of systemic toxicity, other than the potential for ground-water ingestion exposures among residents at some point in the future. This report points out that the future residential ground-water ingestion threat becomes insignificant if the risk model is modified to account for the likelihood of the small portion of the aquifer that is effected being developed as a potable water supply.

Because of the need to comply with relevant and appropriate standards of the Safe Drinking Water Act, however, the risk estimate for this potential exposure pathway is moot. There is thus no need for further refinement of any systemic toxicity risk estimates.

Table 4-1 provides a summary of the cancer risk estimates for Monsanto's Soda Springs Plant. Estimates for the occupational exposure scenario are discussed in Subchapter 4.1; estimates for the residential exposure scenario are discussed in Subchapter 4.2.

4.1 Occupational Scenario

Current occupational risk estimates are summarized in Section 4.1.1. Occupational risk estimates for future site conditions are discussed in Section 4.1.2.

4.1.1 Current Occupational Subscenario

The deterministic risk assessment provides predictions of risk for six subpopulations exposed to different on-site materials containing concentrations of ^{226}Ra that are elevated relative to background soil. All six subpopulation estimates are incremental lifetime cancer rates (ILCRs) on the order of 10^{-4} . A stochastic assessment provides a prediction of risk for the population of permanent, full-time employees, ILCR_{occ} . The 95th percentile of this estimate, $\text{ILCR}_{\text{occ},0.95}$, is also on the order of 10^{-4} . Although the deterministic and stochastic assessments are not directly comparable (*i.e.*, subpopulation estimates vs. a population estimate), the results of both are in agreement—current high-end risk estimates for workers do not exceed the remedial action threshold of 10^{-4} .

Table 4-1. Summary and Comparison of Cancer Risk Estimates.

Scenario/Subscenario	Deterministic Baseline Risk Assessment	Stochastic Baseline Risk Assessment
	Incremental Lifetime Cancer Rate	
Occupational Scenario		
current subscenario, $ILCR_{occ}$ (external γ -radiation associated with ^{226}Ra in on-site materials)	7×10^{-5} to $5 \times 10^{-4} \dagger$	$p_{0.95} = 8 \times 10^{-5} *$
future subscenario, $ILCR_{occ}$ — Monsanto's perspective, that future conditions are well and conservatively approximated by current conditions (external γ -radiation associated with ^{226}Ra in on-site materials)	1×10^{-3} to $2 \times 10^{-3} \dagger \S$	$p_{0.95} = 8 \times 10^{-5} *$
future subscenario, $ILCR_{focc,34,EPA}$ — worst-case evaluation of EPA-10's perspective, a subpopulation of unshielded workers on the slag pile (external γ -radiation associated with ^{226}Ra in on-site materials) \S	2×10^{-3}	$p_{0.95} = 5 \times 10^{-5}$
Residential Scenario		
current subscenario, $ILCR_{cres}$ — 0.5 mi west of the plant (ingestion of As in soil)	0^{\ddagger}	$p_{0.95} = 2 \times 10^{-8} \ddagger$
current subscenario, $ILCR_{cres,be}$ — 0.5 mi west of the plant (ingestion of Be in soil)	$2 \times 10^{-6}^{\ddagger}$	$p_{0.95} = 4 \times 10^{-8} \ddagger$
future subscenario, $ILCR_{fres}$ — Monsanto's perspective, that land use and zoning will affect spatial patterns of development on land with residential potential (external γ -radiation associated with ^{226}Ra in soil) \S	6×10^{-6} to $2 \times 10^{-3} \diamond$	$p_{0.95} = 3 \times 10^{-7} \ddagger$
future subscenario, $ILCR_{fres,EPA}$ — EPA-10's perspective, that land use and zoning will not affect spatial patterns of development on land with residential potential (external γ -radiation associated with ^{226}Ra in soil) \S	6×10^{-6} to $2 \times 10^{-3} \diamond$	$p_{0.95} = 1.0 \times 10^{-6} \ddagger$
future subscenario, $ILCR_{fres,74}$ — worst-case evaluation for a subpopulation of residents living at the north fence line (external γ -radiation associated with ^{226}Ra in soil) \S	2×10^{-3}	$p_{0.95} = 5 \times 10^{-6}$

\dagger The range of conservative estimates for worker subpopulations stationed at various stockpiled materials and roads; virtually all risk is attributable to external γ radiation associated with ^{226}Ra .

$*$ 95th percentile of the estimate for a randomly-selected member of the population of permanent, full-time workers.

\S Risk estimates assume discontinuation of Monsanto operations.

\ddagger Conservative estimate for the only area within the vicinity of the plant that currently has residents; ingestion of As constitutes a major pathway for all three locations evaluated, while ingestion of Be constitutes a major pathway for the area west of the plant, the area which actually has residents.

\diamond 95th percentile of the estimate for a randomly-selected member of the population of residents in the vicinity of the plant.

\diamond The range of conservative estimates for resident subpopulations located at sites to the north and south of the plant.

The stochastic assessment provides a conservative estimate of the incremental lifetime one can expect to lose by working full time at the plant and thus risking the development of an occupational cancer—3 hours (relative to 2 years, on average, for someone who does not work at the plant). The stochastic evaluation indicates that the workers who are most at risk are those operating heavy equipment in the beneficiation area and on the slag pile.

Further refinement of the $ILCR_{occ}$ input variables is not likely to be useful because natural variability dominates the uncertainty in the variables to which the model is most sensitive. Some refinement could be achieved by modifying the model structure to allow for more realistic evaluations of exposure. Such modifications include time stepping, accounting for exposures at multiple locations, and accounting for someone holding different jobs during their tenure of plant employment. Such restructuring of the model would be expected to narrow the $ILCR_{occ}$ output (*i.e.*, increase low-end risk estimates and decrease high-end estimates) somewhat.

4.1.2 Future Occupational Subscenario

Monsanto's perspective on future occupational conditions is that they are well and conservatively approximated by current conditions. The $ILCR_{occ,0.95}$ of 10^{-4} is thus regarded as the high-end risk estimate for this subscenario, also. EPA-10, however, has concerns about the degree of risk that could be anticipated should Monsanto cease operations and another company take over the plant. The agency has proposed a future subscenario where everyone works in jobs that provide no shielding from gamma radiation. The deterministic assessment predicts ILCRs, for the six subpopulations referred to in Section 4.1.1, that are all on the order of 10^{-3} , an order of magnitude above both the remedial action threshold and $ILCR_{occ,0.95}$, for this version of the future occupational subscenario.

A stochastic assessment of EPA-10's perspective—conducted, for conciseness, only for the worst-case location, the slag pile (grid 34)—yields an $ILCR_{focc,34,EPA,0.95}$ estimate of 10^{-4} . This result indicates that the deterministic estimates for this subscenario are too conservative. It also indicates that scenario uncertainty regarding future exposures is not very important (*i.e.*, the $ILCR_{occ}$ model is quite robust).

4.2 Residential Scenario

Current residential risk estimates are summarized in Section 4.2.1. Residential risk estimates for future conditions are discussed in Section 4.2.2.

4.2.1 Current Residential Subscenario

Ingestion of As and Be present in surface soil at elevated concentrations accounts for much of the deterministic ILCR estimates for three subpopulations conducted for this subscenario (SAIC, 1995). However, within the near vicinity of the plant, people currently reside only in an area located about 0.5 miles to the west. Within the context of scope, the stochastic population assessment thus converges to the deterministic subpopulation assessment for this location; with the exception of methodological difference, the two assessments are directly comparable.

The deterministic assessment yields an ILCR for As ingestion of 0 and an ILCR for Be ingestion on the order of 10^{-6} . The respective estimates from the stochastic assessment, $ILCR_{\text{cres}}$ and $ILCR_{\text{cres,be}}$, are both on the order of 10^{-8} . These low estimates, all of which are far below the remedial action threshold, are attributable to a lack of discernably elevated concentrations of As and Be in soil, relative to background conditions, at the location of the residences.

4.2.2 Future Residential Subscenario

The deterministic assessment evaluates subpopulations at four locations, with ILCR estimates ranging from 10^{-5} to 10^{-3} . The lowest estimate is for a subpopulation well south of the plant; an estimate on the order of 10^{-4} applies to a subpopulation to the near northwest of the plant; and, 10^{-3} applies to subpopulations adjacent to the plant's north and south fence lines (SAIC, 1995). Monsanto's perspective on future residential conditions within the near vicinity of the plant is that land having residential development potential will be developed in such a way that the relative spatial density of inhabitants will be affected by land use and zoning. Within this perspective, a stochastic population estimate of $ILCR_{\text{fres},0.95}$ is on the order of 10^{-7} , which is substantially lower than the corresponding deterministic subpopulation estimates.

EPA-10's perspective on future development in the area of the plant is that land with residential potential will be developed with a uniform spatial density of inhabitants. A stochastic population estimate of this perspective, $ILCR_{fres,EPA,0.95}$, is on the order of 10^{-6} . To obtain an estimate that, with the exception of methodology, is directly comparable to EPA-10's north fence line subpopulation estimate (grid 74), a subpopulation assessment was conducted that yields an $ILCR_{fres,74,0.95}$ that is also on the order of 10^{-6} . These additional evaluations allow for the assessment of scenario uncertainty. While such uncertainty does exist, the stochastic results, regardless of perspective, indicate that the deterministic results are too conservative and that high-end estimates of potential future residential risks are far below the remedial action threshold.

Appendices



MONTGOMERY WATSON

Appendices

List of Appendices

- Appendix A Comparison of Two Versions of an Occupational Cancer Risk Model
- Appendix B Evaluation of Weekly Exposure Frequency and Exposure Time Data
- Appendix C Derivation of Job-Specific Dose-Reduction Factors from Gamma Shielding Measurements
- Appendix D Kriging Results for Radium-226 Concentrations in On-Site Soils and Summary of Kriging Methodology
- Appendix E Analytical Results for Radium-226 Concentrations in On-Site Materials
- Appendix F Crystal Ball® Report—Occupational Cancer Risk Model
- Appendix G Grid-Specific Results for the Occupational Cancer Risk Model
- Appendix H Job-Specific Results for the Occupational Cancer Risk Model
- Appendix I Crystal Ball® Report—EPA's Perspective on a Future Occupational Cancer Risk Model for the Subpopulation of Workers on the Slag Pile
- Appendix J Comparison of Two Versions of Residential Cancer Risk Models
- Appendix K Kriging Results for Arsenic Concentrations in Surface Soil
- Appendix L Crystal Ball® Report—Current Residential Cancer Risk Model
- Appendix M Grid-Specific Results for the Current Residential Cancer Risk Model
- Appendix N Crystal Ball® Report—Current Residential Cancer Risk Model (Beryllium Ingestion Version)
- Appendix O Kriging Results for Radium-226 Concentrations in Surface Soil
- Appendix P Derivation of a Thin-Shell Geometry Factor for External Gamma Radiation Exposures
- Appendix Q Crystal Ball® Report—Future Residential Cancer Risk Model
- Appendix R Grid-Specific Results for the Future Residential Cancer Risk Model
- Appendix S Crystal Ball® Report—EPA's Perspective on the Future Residential Cancer Risk Model
- Appendix T Grid-Specific Results for EPA's Perspective on the Future Residential Cancer Risk Model
- Appendix U Crystal Ball® Report—Future Residential Cancer Risk Model for the Worst-Case Subpopulation Along the North Fence Line

Appendix A



MONTGOMERY WATSON

Appendix A

Comparison of Two Versions of an Occupational Cancer Risk Model

Occupational Cancer Risk Model for Monsanto Company's Elemental Phosphorus Plant Soda Springs, Idaho

The following is a comparison of two versions of the current occupational cancer risk model for the Monsanto Soda Springs Plant. The model has been simplified to focus only on external gamma radiation exposures attributable to radium-226, as preliminary work performed by Science Applications International Corporation has demonstrated that this is the only constituent-pathway element of the model which contributes significantly to the overall site risk estimate for the occupational scenario.

Version 1—United States Environmental Protection Agency, Region 10, and Science Applications International Corporation

$$ILCR_{occ,m} = \frac{SF_{Ra,res} \times (EF_{occ} \times ET_{occ}) \times ED_{occ} \times \left([^{226}Ra]_m \times DRF \right) - [^{226}Ra]_b \times F_m}{UCF_{t1} \times UCF_{t2}}$$

Each of the model variables and invariate parameters are defined below:

- $ILCR_{occ,m}$: incremental lifetime cancer rate attributable to external gamma radiation emitted from elevated levels of radium-226 in material m stockpiled at the plant (unitless).
- $SF_{Ra,res}$: cancer potency slope factor for general population exposures to external gamma radiation derived from radium-226 (g/[pCi·yr]).
- $EF_{occ} \times ET_{occ}$: product of occupational exposure frequency (*i.e.*, days of on-the-job exposure per year) and occupational exposure time (*i.e.*, hours of on-the-job exposure per day) (hr/yr).
- ED_{occ} : occupational exposure duration (yr).
- $[^{226}Ra]_m$: concentration of radium-226 in material m (pCi/g).
- DRF_m : dose-reduction factor (*i.e.*, shielding factor for gamma radiation) that is specific to the type of work being performed in the vicinity of material m (unitless).
- $[^{226}Ra]_b$: background concentration of radium-226 in soil (pCi/g).
- F_m : material-specific fraction of the time spent outdoors on the job (unitless).
- UCF_{t1} : time unit conversion factor #1 (hr/d).
- UCF_{t2} : time unit conversion factor #2 (d/yr).

Version 2—Monsanto Company and Montgomery Watson

$$ILCR_{occ,g,j} = \frac{SF_{Ra,occ} \times (EF_{occ} \times ET_{occ}) \times ED_{occ} \times \left([^{226}Ra]_g \times DRF_j - [^{226}Ra]_b \right) \times F_{g,j}}{UCF_{t1} \times UCF_{t2}} \times UF_{dre}$$

Each of the model variables and invariate parameters are defined below:

- $ILCR_{occ,g,j}$: incremental lifetime cancer rate—within a particular grid and for a particular job category—attributable to external gamma radiation emitted from elevated levels of radium-226 in soil, materials stockpiles, and roads at the plant (unitless).
- $SF_{Ra,occ}$: cancer potency slope factor for occupational population exposures to external gamma radiation derived from radium-226 [$g/(pCi \cdot yr)$].
- $EF_{occ} \times ET_{occ}$: the product of occupational exposure frequency and occupational exposure time (hr/yr).
- ED_{occ} : exposure duration; (yr).
- $[^{226}Ra]_g$: grid-specific concentration of radium-226 in, as appropriate, soil, relevant materials stockpiles, and roads (pCi/g).
- DRF_j : job-specific dose-reduction factor (*i.e.*, shielding factor for gamma radiation) (unitless).
- $[^{226}Ra]_b$: background concentration of radium-226 in soil (pCi/g).
- $F_{g,j}$: grid- and job-specific fraction of the average time spent outdoors on the job (unitless).
- UCF_{t1} : time unit conversion factor #1 (hr/d).
- UCF_{t2} : time unit conversion factor #2 (d/yr).
- UF_{dre} : uncertainty factor for dose-rate effectiveness associated with high-dose-to-low-dose and instantaneous-dose-to-protracted-dose extrapolations (unitless).

In order to estimate the risk for an individual selected at random from the work force, $ILCR_{occ}$, each $ILCR_{occ,g,j}$ is sampled randomly in weighted fashion where the weighting factor, WF, is:

$$WF = P_{w,g} \times P_{g,j}$$

where:

- $P_{w,g}$: proportion of the permanent, full-time occupational work force assigned to a specific grid such that $\sum_g P_w = 1.00$ (unitless).

- $P_{g,j}$: grid-specific proportion of individuals within a particular job category such that $\sum_j P_g = 1.00$ (unitless).

Summary

The two models have the same general structure. The second version of the model was developed for use in a stochastic analysis, as opposed to the deterministic analysis used with the first version. Other refinements associated with the second version include:

- $ILCR_{occ}$ is specific to the entire population of full-time, permanent workers at the plant (actually for an individual selected at random from this work force), as opposed to various small, minority subpopulation of the work force.
- $SF_{Ra,occ}$ is specific to occupational populations, rather than to general residential populations.
- $[^{226}Ra]$ is from all occupied portions of the site on a location-specific basis, not just from a particular stockpile of material.
- UF_{dre} is added to account for uncertainty in using high-dose and instantaneous-dose radiation data to predict effects at the very low, protracted, and fractionated doses of radiation experienced at the plant.

Appendix B



MONTGOMERY WATSON

Appendix B

Evaluation of Weekly Exposure Frequency and Exposure Time Data

Analysis of Monsanto Soda Springs Plant Exposure Time/Frequency Data

Week	Total On-Site Occupational Time Per Employee (hr)																
	04. 05-01/02	004. 007	011. 012	016. 017	021. 022	026. 027	036. 037	041. 042	051. 052	056. 057	06. 007	086. 087	096. 097	106. 107	011. 012	016. 017	121. 122
1	44	43.5	23.5	24	28	30	40	39	40	32	30	45	37.5	40.75	23.5	24	44.5
2	40	42.5	56	8	41	36	46	34.5	88	40	41	45	41	55.5	56	8	40
3	52	51	52	32	40	83	40	44	24	16	40	39	8	34	52	32	25
4	32	34	32	40	48	76	40	76	30	52	48	44	34	43	32	40	0
5	24	46.5	40	40	48	36	48	52	40	42	42	25	22	10.75	40	40	46.5
6	12	42.5	52	48	40	9	0	45	40	40	41	53	40	46.75	52	48	25
7	60	51.5	44	32	48	45	40	0	48	40	44	20	39	21.75	44	32	44
8	32	34	48	40	32	46	40	44	44	32	40	37	15	36	48	40	35
9	46	51.5	24	40	40	0	40	18	0	0	40	27	15	33.5	24	40	36
10	40	43.5	40	48	40	24	24	0	0	24	45	19	27	0	40	48	0
11	48	51	40	32	52	NA	40	40	40	42	44	46	43	44.25	40	32	41
mean	39	45	41	35	42	39	36	35	35	32	41	35	28	32	41	35	30
standard deviation	13.5	6.5	11.0	11.5	7.2	26	14.1	24	25.2	15.0	4.7	11.9	12.2	18.9	11.8	12.0	17.3
variance	182	42	120	131	52	681	198	554	636	226	22	141	148	286	134	145	299
Overall Statistics																	
sample size	17																
mean mean	37	in hr/wk															
	1,900	in hr/yr															
mean standard deviation	3.7	in hr/wk															
	194	in hr/yr															
lower bound	0	in hr/wk	(physical constraint: minimum number of hr/wk)														
	0	in hr/yr	(physical constraint: minimum number of hr/yr)														
upper bound	168	in hr/wk	(physical constraint: maximum number of hr/wk)														
	8,766	in hr/yr	(physical constraint: maximum number of hr/yr)														
alpha*	75																
beta*	270																
distribution**	beta(75, 270, 0, 8,766) hr/yr																
*Shape parameters for a beta distribution																	
**A beta distribution was chosen with maximum-entropy inference																	

Appendix C



MONTGOMERY WATSON

Appendix C

Derivation of Job-Specific Dose-Reduction Factors from Gamma Shielding Measurements

MEMORANDUM



MONTGOMERY WATSON

To: Bob Geddes, Monsanto

Date: November 16, 1994

From: Bill Wright *Wright*

Job No.: 1183.0040

Subject: Dose-Reduction Factors

This memorandum summarizes the recent discussions regarding dose-reduction, or shielding, factors (DRFs) applicable to external gamma radiation exposures at the Monsanto Soda Springs Plant.

In calculating DRFs, we are dealing with two or more different types of background:

- Cosmic radiation, which is very energetic to the point of being, for our purposes, essentially unshieldable; and,
- Terrestrial gamma radiation in areas unaffected by past or present plant operations, which, for our purposes, consists virtually entirely of gamma radiation derived from ^{226}Ra and its daughter isotopes (subsequent reference herein to ^{226}Ra is meant to include its daughter isotopes).

Shield material has inherent gamma activity; however, when we introduce a shield we essentially substitute one source for another (hopefully less intensive) source. As such, I think it is proper to focus only on the net reduction in radiation obtained with a shield.

Both cosmic radiation and ^{226}Ra affect the measurements IT used to obtain the dose rates we're using to calculate DRFs. If we assume that the vehicle or heavy equipment shields do not attenuate the cosmic radiation, and if we wish to calculate their effect on attenuation of gamma radiation from ^{226}Ra , then it seems proper to subtract out cosmic radiation from both the unshielded and shielded measurements:

$$DRF = \frac{\gamma_s - \gamma_c}{\gamma_u - \gamma_c}$$

In the above equation, γ_u represents the measured unshielded dose rate in $\mu\text{rem/hr}$, γ_c represents the amount of that dose rate, in $\mu\text{rem/hr}$, that is attributable to cosmic radiation (a good average value for which IT should be able to derive based on site elevation), and γ_s represents the shielded dose rate, in $\mu\text{rem/hr}$, at the same location. This equation thus evaluates the effectiveness of the shield in reducing terrestrial (*i.e.*, ^{226}Ra) gamma radiation exposures.

In the external exposure risk model, DRF is a variable used to reduce the concentration of ^{226}Ra in soil to account for the effect of the shield. If we define $\{^{226}\text{Ra}\}_s$ as the effective soil concentration of ^{226}Ra and $[^{226}\text{Ra}]_s$ as the actual soil concentration of ^{226}Ra , the two are related as:

$$\{^{226}\text{Ra}\}_s = DRF \times [^{226}\text{Ra}]_s$$

As we are interested in the incremental increase of gamma radiation attributable to levels of ^{226}Ra elevated by plant operations, past or present, we must subtract the background soil concentration of ^{226}Ra , $[^{226}\text{Ra}]_{s,\text{bkg}}$, from the effective concentration; in other words, the net effective concentration, $\{^{226}\text{Ra}\}_{s,\text{net}}$, is:

$$\{^{226}\text{Ra}\}_{s,\text{net}} = \{^{226}\text{Ra}\}_s - [^{226}\text{Ra}]_{s,\text{bkg}}$$

It is this term that is used in the external exposure risk model. The mathematical summary of this issue is as follows:

$$\{^{226}\text{Ra}\}_{s,\text{net}} = \left(\frac{\gamma_s - \gamma_c}{\gamma_u - \gamma_c} \times [^{226}\text{Ra}]_s \right) - [^{226}\text{Ra}]_{s,\text{bkg}}$$

Two separate background values appear in the overall equation— γ_c and $[^{226}\text{Ra}]_{s,\text{bkg}}$. The first eliminates the influence of cosmic radiation from the shielding measurements, and the second eliminates the influence of naturally occurring levels of soil radium from the estimate of incremental lifetime cancer risk.

This approach properly addresses IT's concern about background influencing shielding factor estimates, and EPA-10's concern about double subtraction of background.

During our last meeting, EPA-10 and IT expressed concern about using within-background unshielded measurements in estimating DRF statistics. As a result, the four paired measurements within the total background range of at or below 15 $\mu\text{rem/hr}$ have been eliminated from the data set (the data were also evaluated for correlation between unshielded measurements and DRF; no significant correlations were found). New distributions of shielding factors for vehicle operators, DRF_{vo} , and for heavy equipment operators, DRF_{heo} , were derived from the new data set, assuming a cosmic radiation background of 6.0 $\mu\text{rem/hr}$. The shielding factor for unshielded workers, DRF_{uw} , is still assumed to be represented by a point estimate of 1.00.

Estimates of the mean, μ , and standard deviation, σ , were obtained for DRF_{vo} and DRF_{heo} , and, on the basis of physical constraint, lower and upper bounds, λ and ν , of 0 and 1.00 are assumed for both variables. Maximum-entropy inference dictates that the most uncertain distribution—given knowledge constraints of μ , σ , λ , and ν ,—is a beta distribution. The resulting distributions, along with some of the relevant parameters, are:

- DRF_{vo} —

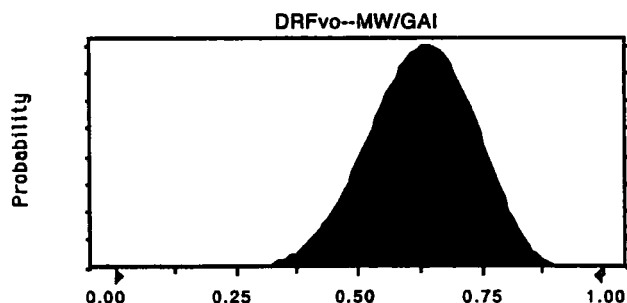
$$\beta(12.4, 7.3, 0, 1.00)$$

$$\mu = 0.63$$

$$\sigma = 0.106$$

$$p_{0.50} = 0.63$$

$$p_{0.95} = 0.80$$



- DRF_{heo} —

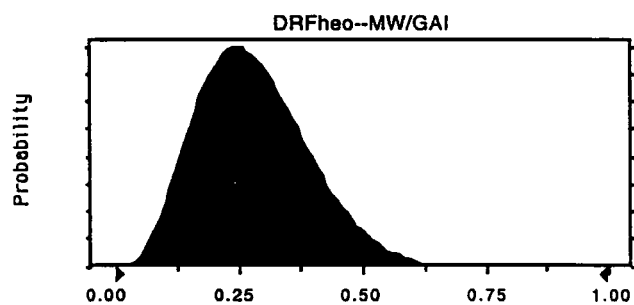
$$\beta(4.4, 11.3, 0, 1.00)$$

$$\mu = 0.28$$

$$\sigma = 0.110$$

$$P_{0.50} = 0.27$$

$$P_{0.95} = 0.48$$



Gamma Radiation Dose-Rate Measurements
Monsanto Company's Elemental Phosphorus Plant
Soda Springs, Idaho
3-Aug-94

Dose Rate (microrem/hour)		Shielding Factor*	Type of Shielding	Location (grid no.)	Location Description and Comments
Unshielded	Shielded				
32	20	0.54	automobile	44	outside service building
48	22	0.38	pot carrier	44	outside #8 furnace
45	15	0.23	pot carrier	44	west of #8 furnace; pot full
35	11	0.17	pot carrier	34	slag dump; metal ramp w/ pot full and empty
45	17	0.28	pot carrier	44	west of #8 furnace
10	10	-	pot carrier	44	#8 furnace alley (not used in calculations**)
38	25	0.59	automobile	34	road on slag pile to slag dump
50	30	0.55	automobile	34	metal thumper
45	25	0.49	dump truck	34	metal thumper
15	15	-	automobile	45	coke pile (not used in calculations**)
6	6	-	automobile	55	quartzite pile (not used in calculations**)
53	21	0.32	ore truck	65	ore pile
40	25	0.56	automobile	65	ore pile
51	35	0.64	automobile	65	ore pile
52	39	0.72	automobile	65	ore pile, blend 1
60	40	0.63	pickup	65	ore pile, blend 1
65	15	0.15	D9 cat	65	ore pile, blend 1
58	40	0.65	automobile	75	underflow solids
40	25	0.56	automobile	76	baghouse dust
40	15	0.26	dump truck	76	baghouse dust
45	35	0.74	automobile	74	electrode seal pond
42	22	0.44	automobile	73	sanitary landfill
45	30	0.62	automobile	63	sanitary landfill
75	50	0.64	automobile	64	nodule area; between two stockpiles
48	25	0.45	automobile	64	treater dust
10	10	-	automobile	54	fuel tanks (not used in calculations**)
43	35	0.78	automobile	54	kiln
43	22	0.43	front-end loader	54	kiln
52	40	0.74	automobile	44	nodule screening pile
52	15	0.20	ore truck	44	nodule screening pile
60	17	0.20	front-end loader	44	nodule loading
45	35	0.74	automobile	53	old underflow solids
35	30	0.83	automobile	53	effluent settling pond; slag grave
60	38	0.59	automobile	23	sewage evaporation pond

*1.00 denotes no shielding, and 0 denotes complete shielding; this factor was calculated by subtracting the cosmic radiation dose rate of 6 from both the unshielded and shielded dose rates.

**This sample was not used in calculation of shielding-factor statistics as the unshielded dose rate is at the cosmic radiation background level.

Note: The shielding factor is not correlated with the unshielded dose rate ($r = -0.16$).

Shielding-Factor Statistics

	DRF _{un}	DRF _{sh}
	0.54	0.38
	0.59	0.23
	0.55	0.17
	0.56	0.28
	0.64	0.49
	0.72	0.32
	0.63	0.15
	0.65	0.26
	0.56	0.43
	0.74	0.20
	0.44	0.20
	0.62	
	0.64	
	0.45	
	0.78	
	0.74	
	0.74	
	0.83	
	0.59	
mean	0.63	0.28
std. deviation	0.106	0.110
lower bound	0	0
upper bound	1.00	1.00
alpha	12.4	4.4
beta	7.3	11.3
p0.95	0.80	0.48
distribution	beta(12.4, 7.3, 0, 1.00)	beta(4.4, 11.3, 0, 1.00)

Appendix D



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Appendix D

Kriging Results for Radium-226 Concentrations in On-Site Soils and Summary of Kriging Methodology

**Grid-Specific Statistics for Radium-226 Soil
Concentrations Within the Monsanto Soda Springs Plant**

<u>Grid**</u>	<u>[Ra-226]g (pCi/g)*</u>	
	<u>Mean</u>	<u>Standard Deviation</u>
23	2.4	0.85
24	3.4	1.20
25	3.0	1.27
33	2.7	1.16
34	3.5	1.69
35	3.3	1.54
43	3.3	1.60
44	3.5	1.91
45	3.7	1.91
46	2.9	1.48
53	3.5	1.73
54	4.6	2.5
55	4.0	2.1
56	3.0	1.52
63	4.8	2.0
64	5.2	2.6
65	4.6	2.3
66	2.9	1.27
73	5.1	1.97
74	5.6***	2.2
75	5.1	1.89
76	3.0	1.12
77	1.68	0.74
background	1.70	0.50

*Grid-specific concentrations of radium-226 in soil.

**Grids that lie, at least in part, within the plant fenceline.

***The highest mean estimated for all 81 grids covering the plant and the near vicinity; the lowest is 1.11 pCi/g.

Kriging Methodology

Jeanne Simpson
Golder Associates Inc.
September 6, 1994

Surface soil quality data were obtained from irregularly spaced sampling locations within a one-to-two-mile radius of the Monsanto plant. Ordinary kriging was used to calculate soil concentrations throughout the 81-grid study area used for analysis of potential receptor impacts at and in the near vicinity of the plant. Ordinary kriging produces a weighted average—the best linear unbiased estimator—of the soil samples in or near the grid of interest. The derivation of ordinary kriging weights takes into consideration the proximity of the soil samples to the grid of interest and the covariance structure of the soil data. Additionally, kriging provides an estimate of the standard deviation of the prediction. A complete description of the kriging techniques used is provided in Isaaks and Srivastava (1989).

The EPA model GEO-EAS (GEOstatistical Environmental Assessment Software) was used to perform the ordinary kriging (EPA, 1991). Development of the ordinary kriging estimate is a two-step process:

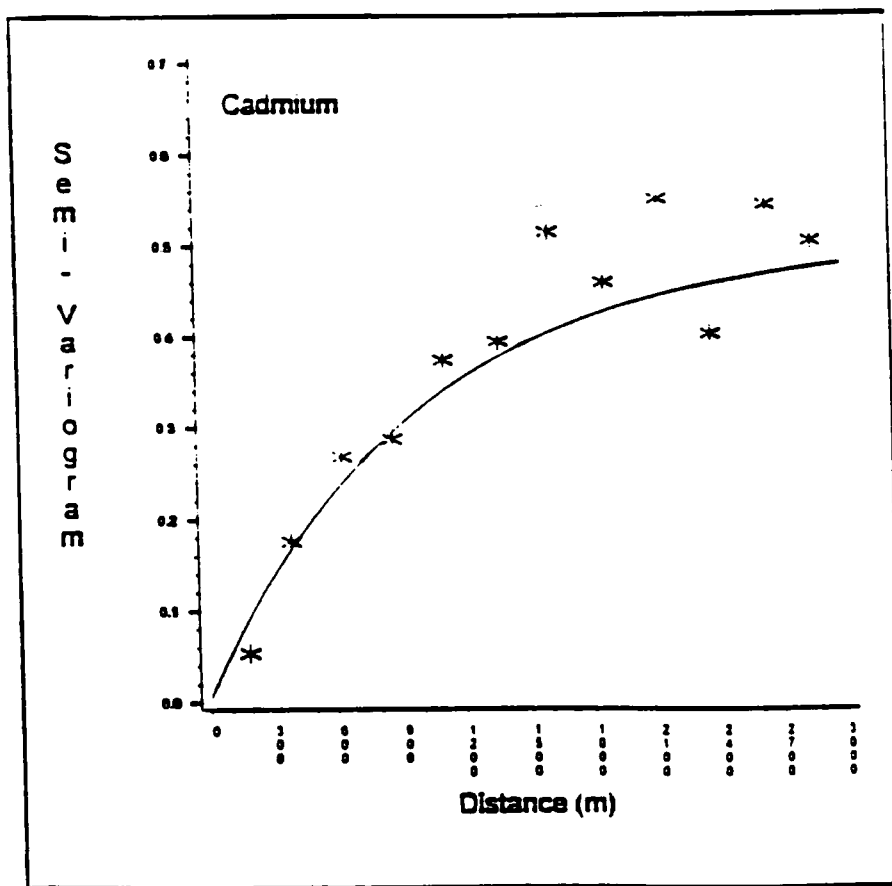
1. The covariance structure is estimated using a semi-variogram which describes the relationship of the squared differences between pairs of observations and the intervening distance between them.
2. A system of linear equations are solved.

The ordinary kriging is performed on the logarithms (base 10) of the soil quality values.

Figure D-1 shows, as an example, the estimated semi-variogram for cadmium in soil. A model is fit to the estimated semi-variogram. If there were no spatial relationship, the model would be a straight line parallel to the distance axis (*i.e.*, the variability between two points would be independent of distance). For all the soil constituents, an exponential model fit the estimated semi-variograms:

$$\gamma(h) = \text{SILL} \left[1 - e^{-3|h|/\text{RANGE}} \right] + \text{NUGGET}.$$

Figure D-1. Semi-variogram for the logarithm (base 10) of cadmium (exponential model with a nugget of 0.005, a sill of 0.5, and a range of 3,000 meters).



The parameters of these exponential models and correlations, for radium-226 and arsenic (the results for which are provided in Appendix J), are:

<u>Constituent</u>	<u>Nugget</u>	<u>Sill</u>	<u>Range (m)</u>	<u>Correlation</u>
radium-226	0.120	0.120	3,000	0.32
arsenic	0.030	0.170	4,000	0.61

The dependent variable in the above equation is the semi-variogram at distance h . The nugget is the size of the jump discontinuity that occurs at zero distance; it is often described as the small scale variability or the variance between two samples if it were possible to take two samples at identical locations. The sill is the upper bound on the variability, and the range is the distance between two points where the spatial correlation is effectively zero.

Concentrations of constituents in the environment are often well characterized by lognormal probability distributions (Gilbert, 1987), which can be described in terms of a geometric mean and geometric standard deviation. These values are, respectively, the exponentiated mean and standard deviation calculated using the logarithms of the data, and are the values presented on p. D-1 (for radium-226 in soil on site) and in Appendix J (for arsenic) and Appendix M (for radium-226 in all grids, on and off site).

Literature Cited

EPA, 1991, User's Guide: *GEO-EAS v. 1.2.1 (Geostatistical Environmental Assessment Software)*, Environmental Monitoring Systems Laboratory, Las Vegas, Nevada.

Gilbert, R. O., 1987, *Statistical Methods for Environmental Pollution Monitoring*, Van Nostrand Reinhold Company, New York, New York.

Isaaks, E. H., and R. M. Srivastava, 1989, *Applied Geostatistics*, Oxford University Press, New York, New York.

Appendix E



MONTGOMERY WATSON

Appendix E

Analytical Results for Radium-226 Concentrations in On-Site Materials

**Material-Specific Statistics for Radium-226
Concentrations at the Monsanto Soda Springs Plant**

<u>Material</u>	<u>[Ra-226]m (pCi/g)*</u>	
	<u>Arithmetic Mean</u>	<u>Arithmetic Standard Deviation</u>
baghouse dust	20	16.0
coke	0.20	0.110
new nodules	50	2.1
old nodules	41	1.00
ore blend #1	32	3.5
ore blend #2	29	1.15
quartzite	0.047	0.025
roads	30	1.00
slag	48	5.7
treater dust	20	6.5
underflow solids	38	3.8

*Material-specific concentrations of radium-226.

Appendix F



MONTGOMERY WATSON

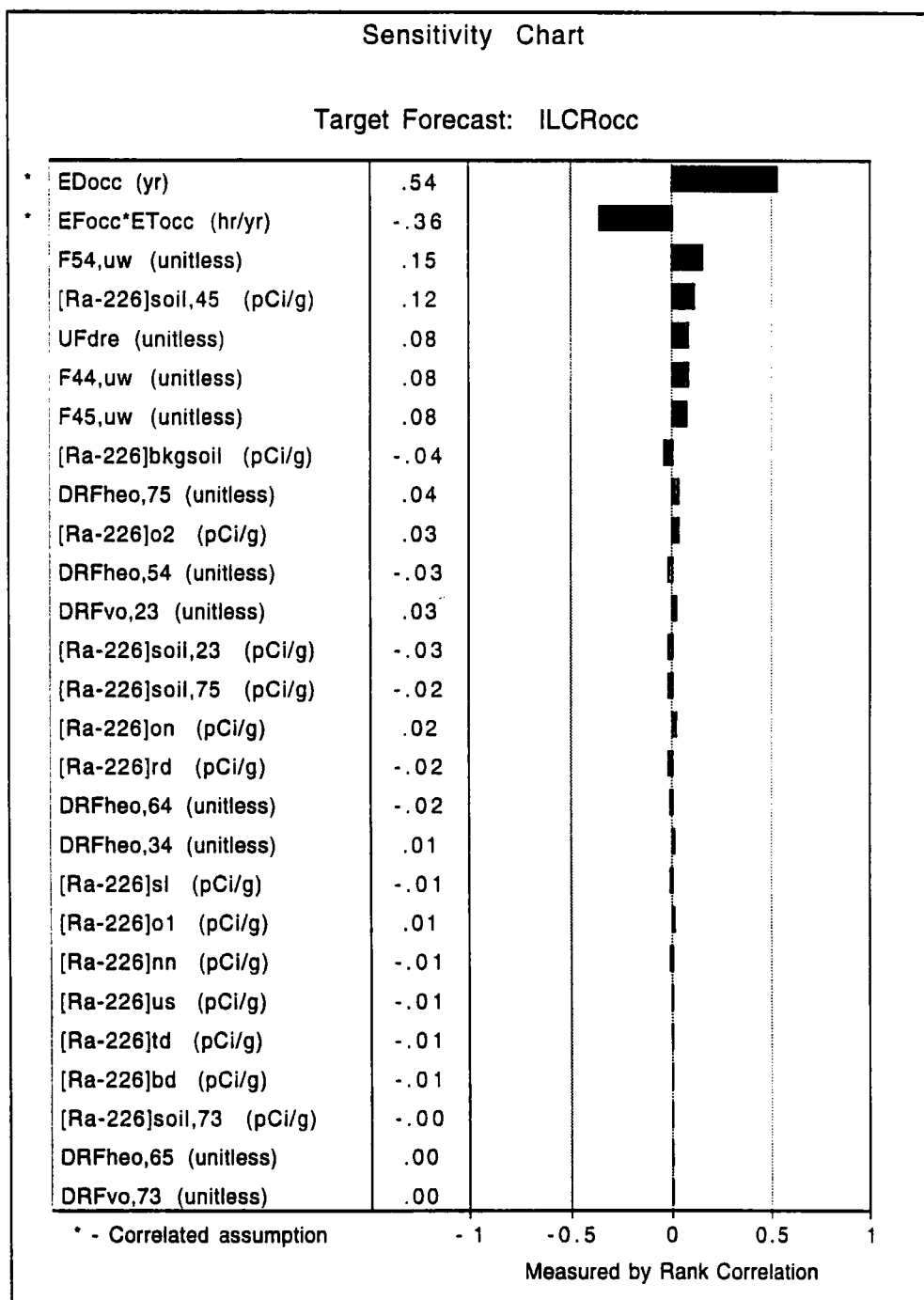
Appendix F

Crystal Ball® Report—Occupational Cancer Risk Model

Crystal Ball Report: Occupational Scenario for Monsanto's Soda Springs Plant

Simulation started on Thu, Feb 15, 1996 at 9:38:03

Simulation stopped on Thu, Feb 15, 1996 at 9:54:19



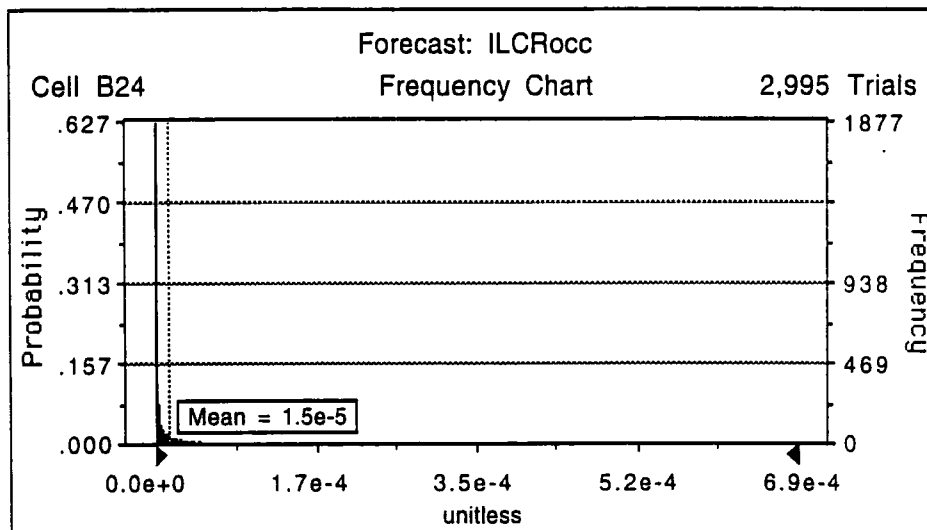
Sum of r-squared values = 0.49

Forecast: ILCRocc

Cell: B24

Statistics:

	<u>Value</u>
Trials	2,995
Mean	1.46E-05
Median	6.4E-07
Standard deviation	4.5E-05
Variance	2.0E-09
Coefficient of variation	3.1



Forecast: ILCR_{occ} (cont'd)

Cell: B24

Percentiles:

<u>Percentile</u>	<u>ILCR_{occ}</u>
0.03%	0
5.00%	1.52E-11
10.00%	1.11E-09
15.00%	6.5E-09
20.00%	1.93E-08
25.00%	4.3E-08
30.00%	7.8E-08
35.00%	1.30E-07
40.00%	2.4E-07
45.00%	3.9E-07
50.00%	6.4E-07
55.00%	1.06E-06
60.00%	1.74E-06
65.00%	2.9E-06
70.00%	4.5E-06
75.00%	7.6E-06
80.00%	1.26E-05
85.00%	2.1E-05
90.00%	3.6E-05
94.30% (Point estimate for treater dust†)	7E-05
95.00%	7.9E-05
98.00%	1.51E-04
99.00% (Point estimate for baghouse dust†)	2E-04
99.00%	2.2E-04
99.47% (Point estimate for nodules†)	3E-04
99.77% (Point estimate for road dust and underflow solids†)	4E-04
99.90%	4.7E-04
99.91% (Point estimate for slag†)	5E-04
99.97%	6.9E-04
> 99.97% (Point estimate for baghouse dust, roac dust, treater dust, and underflow solids*)	1E-03
> 99.97% (Point estimate for nodules and slag*)	2E-03

†Point estimate applies to current exposures

*Point estimate applies to future exposures

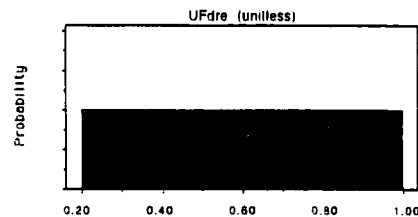
End of Forecast

Assumptions**Assumption: UFDre (unitless)****Cell: B4**

Uniform distribution with parameters:

Minimum	0.20
Maximum	1.00

Mean value in simulation was 0.61

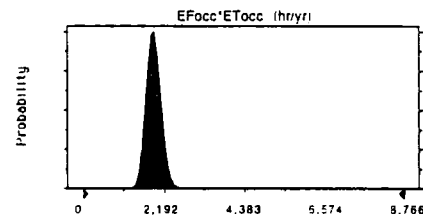
**Assumption: EFocc*ETocc (hr/yr)****Cell: B6**

Beta distribution with parameters:

Alpha	75
Beta	270
Scale	8,766

Selected range is from 0 to 8,766

Mean value in simulation was 1,900



Correlated with:

EDocc (yr) (B7)

-0.71

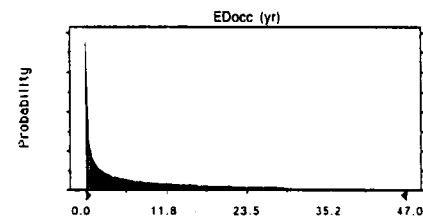
Assumption: EDocc (yr)**Cell: B7**

Beta distribution with parameters:

Alpha	0.40
Beta	1.64
Scale	47

Selected range is from 0 to 47

Mean value in simulation was 9.4



Correlated with:

EFocc*ETocc (hr/yr) (B6)

-0.71

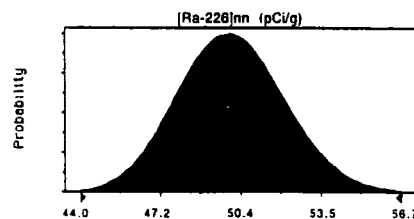
Assumption: [Ra-226]nn (pCi/g)**Cell: B11**

Lognormal distribution with parameters:

Mean	50
Std. deviation	2.1

Selected range is from 0 to ∞

Mean value in simulation was 50

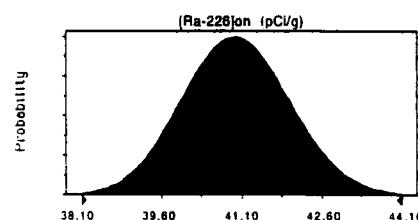
**Assumption: [Ra-226]on (pCi/g)****Cell: B12**

Lognormal distribution with parameters:

Mean	41
Std. deviation	1.00

Selected range is from 0 to ∞

Mean value in simulation was 41

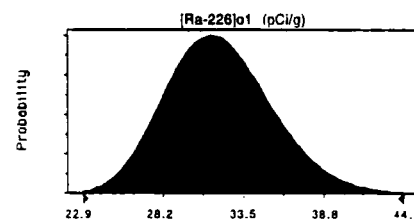
**Assumption: [Ra-226]o1 (pCi/g)****Cell: B13**

Lognormal distribution with parameters:

Mean	32
Std. deviation	3.5

Selected range is from 0 to ∞

Mean value in simulation was 32

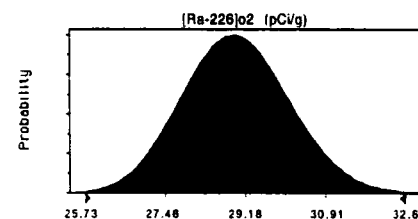
**Assumption: [Ra-226]o2 (pCi/g)****Cell: B14**

Lognormal distribution with parameters:

Mean	29
Std. deviation	1.15

Selected range is from 0 to ∞

Mean value in simulation was 29

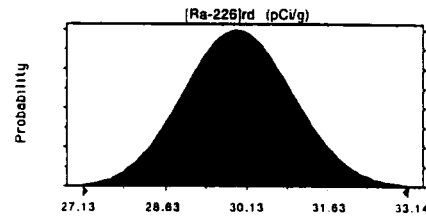


Assumption: [Ra-226]rd (pCi/g)**Cell: B15**

Lognormal distribution with parameters:

Mean	30
Std. deviation	1.00

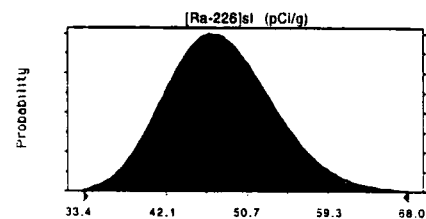
Selected range is from 0 to ∞
 Mean value in simulation was 30

**Assumption: [Ra-226]sl (pCi/g)****Cell: B16**

Lognormal distribution with parameters:

Mean	48
Std. deviation	5.7

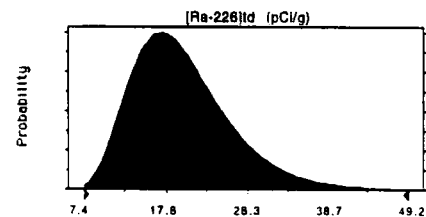
Selected range is from 0 to ∞
 Mean value in simulation was 48

**Assumption: [Ra-226]td (pCi/g)****Cell: B17**

Lognormal distribution with parameters:

Mean	20
Std. deviation	6.5

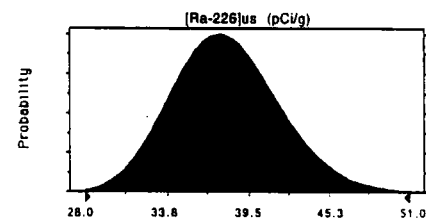
Selected range is from 0 to ∞
 Mean value in simulation was 20

**Assumption: [Ra-226]us (pCi/g)****Cell: B18**

Lognormal distribution with parameters:

Mean	38
Std. deviation	3.8

Selected range is from 0 to ∞
 Mean value in simulation was 38



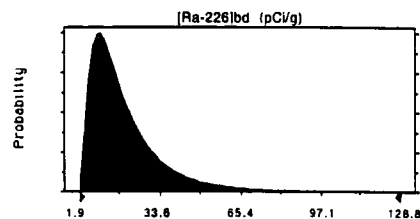
Assumption: [Ra-226]bd (pCi/g)**Cell: B19**

Lognormal distribution with parameters:

Mean	20
Std. deviation	16.0

Selected range is from 0 to ∞

Mean value in simulation was 20

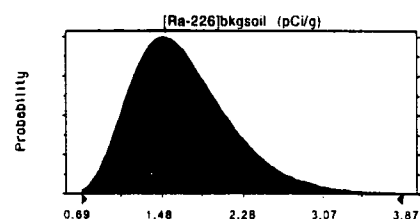
**Assumption: [Ra-226]bkgsoil (pCi/g)****Cell: B20**

Lognormal distribution with parameters:

Mean	1.70
Std. deviation	0.50

Selected range is from 0 to ∞

Mean value in simulation was 1.68

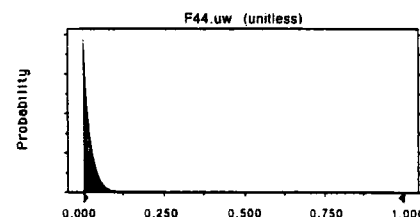
**Assumption: F44,uw (unitless)****Cell: H25**

Beta distribution with parameters:

Alpha	0.98
Beta	46
Scale	1.00

Selected range is from 0 to 1.00

Mean value in simulation was 0.022

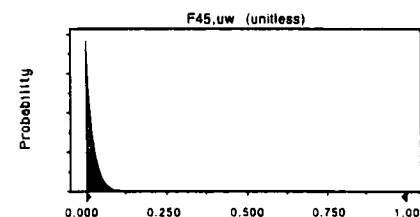
**Assumption: F45,uw (unitless)****Cell: H28**

Beta distribution with parameters:

Alpha	0.98
Beta	46
Scale	1.00

Selected range is from 0 to 1.00

Mean value in simulation was 0.021



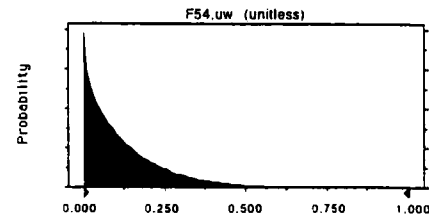
Assumption: F54,uw (unitless)**Cell: H37**

Beta distribution with parameters:

Alpha	0.88
Beta	6.2
Scale	1.00

Selected range is from 0 to 1.00

Mean value in simulation was 0.122

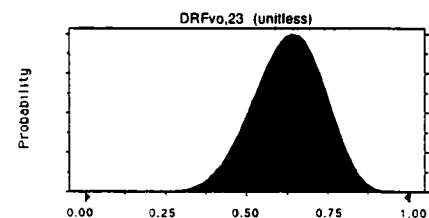
**Assumption: DRFvo,23 (unitless)****Cell: I5**

Beta distribution with parameters:

Alpha	12.4
Beta	7.3
Scale	1.00

Selected range is from 0 to 1.00

Mean value in simulation was 0.63

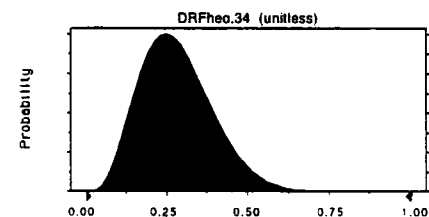
**Assumption: DRFheo,34 (unitless)****Cell: I18**

Beta distribution with parameters:

Alpha	4.4
Beta	11.3
Scale	1.00

Selected range is from 0 to 1.00

Mean value in simulation was 0.28

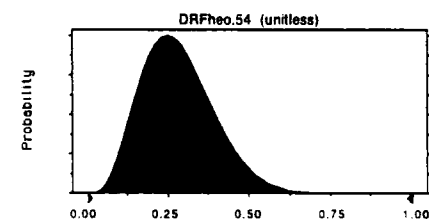
**Assumption: DRFheo,54 (unitless)****Cell: I39**

Beta distribution with parameters:

Alpha	4.4
Beta	11.3
Scale	1.00

Selected range is from 0 to 1.00

Mean value in simulation was 0.28



Assumption: DRFheo,64 (unitless)

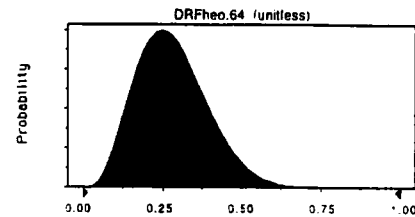
Cell: I51

Beta distribution with parameters:

Alpha	4.4
Beta	11.3
Scale	1.00

Selected range is from 0 to 1.00

Mean value in simulation was 0.28

**Assumption: DRFheo,65 (unitless)**

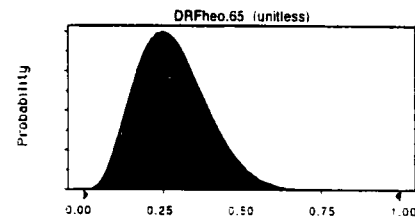
Cell: I54

Beta distribution with parameters:

Alpha	4.4
Beta	11.3
Scale	1.00

Selected range is from 0 to 1.00

Mean value in simulation was 0.28

**Assumption: DRFvo,73 (unitless)**

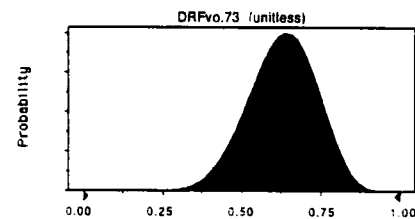
Cell: I59

Beta distribution with parameters:

Alpha	12.4
Beta	7.3
Scale	1.00

Selected range is from 0 to 1.00

Mean value in simulation was 0.63

**Assumption: DRFheo,75 (unitless)**

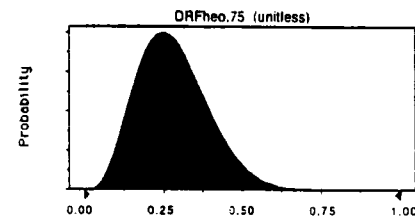
Cell: I66

Beta distribution with parameters:

Alpha	4.4
Beta	11.3
Scale	1.00

Selected range is from 0 to 1.00

Mean value in simulation was 0.28



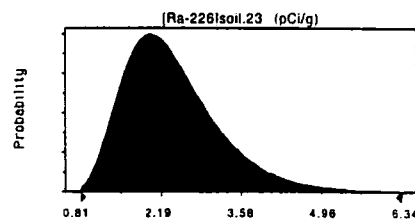
Assumption: [Ra-226]soil,23 (pCi/g)**Cell: J5**

Lognormal distribution with parameters:

Mean	2.4
Std. deviation	0.85

Selected range is from 0 to ∞

Mean value in simulation was 2.4

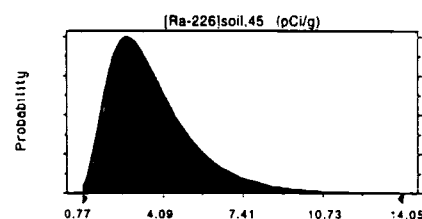
**Assumption: [Ra-226]soil,45 (pCi/g)****Cell: J28**

Lognormal distribution with parameters:

Mean	3.7
Std. deviation	1.90

Selected range is from 0 to ∞

Mean value in simulation was 3.7

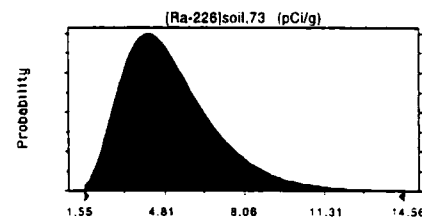
**Assumption: [Ra-226]soil,73 (pCi/g)****Cell: J59**

Lognormal distribution with parameters:

Mean	5.1
Std. deviation	1.97

Selected range is from 0 to ∞

Mean value in simulation was 5.1

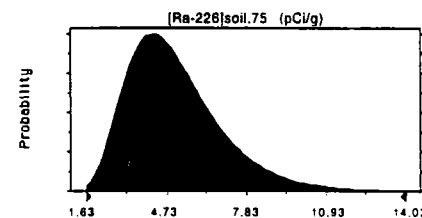
**Assumption: [Ra-226]soil,75 (pCi/g)****Cell: J66**

Lognormal distribution with parameters:

Mean	5.1
Std. deviation	1.89

Selected range is from 0 to ∞

Mean value in simulation was 5.1



End of Assumptions

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	Occupational Cancer Risk Model															
2	Montana Company/Montgomery Watson															
3	Common Dose & Toxicity Factors		Grid	Pw.g	Cumulative Pw.g	Job	Pg	Fg	DRF	[Ra-226]soil.g	[Ra-226]g	Grid- and Job-Specific Dose Factor	ILCRocc.g	Weighted ILCRocc.g	Job	Weighted ILCRocc.g
4	UFdre	1.00	23	0.0066	0.0066	uw	0							3.9E-09	uw	7.6E-04
5	SFRa,occ	0.0000052				vo	1.00	1.00	0.80	2.40	2.40	0.020	5.9E-07		vo	8.5E-07
6	EFocc*ETocc	2.000				heo	0								heo	6.3E-06
7	EDocc	25.0	24	0	0.0066	uw								0		
8	UGFH	24				vo										
9	UGFH2	365.25				heo										
10	Common Dose & Toxicity Factor	3.0E-05	25	0	0.0066	uw								0		
11	[Ra-226]nn	50.0				vo										
12	[Ra-226]on	41.00				heo										
13	[Ra-226]o1	32.0	33	0	0.0066	uw								0		
14	[Ra-226]o2	29.00				vo										
15	[Ra-226]rd	30.00				heo										
16	[Ra-226]sl	48.0	34	0.0198	0.0264	uw	0							2.1E-06		
17	[Ra-226]td	20.0				vo	0									
18	[Ra-226]us	38.0				heo	1.00	1.00	0.80		48.0	36.500	1.1E-03			
19	[Ra-226]bd	20.0	35	0	0.0264	uw								0		
20	[Ra-226]b	1.80				vo										
21						heo										
22	ILCRocc.a	8.3E-04	43	0	0.0264	uw								0		
23	ILCRocc.b	0.0E+00				vo										
24	ILCRocc	8.3E-04				heo										
25	RANDOM	0.7113	44	0.23	0.2564	uw	1.00	1.000	1.00		30.0	28.100	8.3E-04	1.9E-04		
26						vo	0									
27						heo	0									
28			45	0.33	0.5864	uw	1.00	1.000	1.00	3.70	3.70	1.800	5.3E-05	1.8E-05		
29						vo	0									
30						heo	0									
31			46	0	0.5864	uw								0		
32						vo										
33						heo								0		
34			53	0	0.5864	uw										
35						vo										
36						heo										
37			54	0.37	0.9564	uw	0.95	1.000	1.00		30.0	28.100	8.3E-04	3.1E-04		
38						vo	0									
39						heo	0.050	1.00	0.80		30.0	22.100	6.6E-04			
40			55	0	0.9564	uw								0		
41						vo										
42						heo										
43			56	0	0.9564	uw								0		
44						vo										
45						heo										
46			63	0	0.9564	uw								0		
47						vo										
48						heo										
49			64	0.0165	0.9729	uw	0							1.4E-05		
50						vo	0									
51						heo	1.00	1.00	0.80		38.0	28.500	8.5E-04			
52			65	0.0132	0.9861	uw	0							1.1E-05		
53						vo	0									
54						heo	1.00	1.00	0.80		38.0	28.500	8.5E-04			
55			66	0	0.9861	uw								0		
56						vo										
57						heo										
58			73	0.0066	0.9927	uw	0							4.3E-07		
59						vo	1.00	1.00	0.80	5.10	5.10	2.180	6.5E-05			
60						heo	0									
61			74	0	0.9927	uw								0		
62						vo										
63						heo										
64			75	0.0066	0.9993	uw	0							5.6E-06		
65						vo	0									
66						heo	1.00	1.00	0.80	5.10	38.0	28.500	8.5E-04			
67			76	0	0.9993	uw								0		
68						vo										
69						heo										
70			77	0	0.9993	uw								0		
71						vo										
72						heo										
73			23	1.00												

	A	B	C	D	E	F	G	H	I
1	Occupational Cancer Risk Model								
2	Monte Carlo Company/Montgomery Watson								
3	Common Dose & Toxicity Factors		Grid	Pw.g	Cumulative Pw.g	Jcb	Pg	Eg	DRF
4	UPdre	1	23	0.0066	=D4	uw	0		
5	SFra.occ	0.0000052				vo	1	1	0.8
6	EFocc*ETocc	2000				heo	0		
7	EDocc	25	24	0	=D7+E4	uw			
8	UCF11	24				vo			
9	UCF12	305.25				heo			
10	Common Dose & Toxicity Factor	=B4*B5*B6*B7/(B8*B9)	25	0	=D10+E7	uw			
11	(Ra-226)nn	50				vo			
12	(Ra-226)on	41				heo			
13	(Ra-226)o1	32	33	0	=D13+E10	uw			
14	(Ra-226)o2	29				vo			
15	(Ra-226)rd	30				heo			
16	(Ra-226)sl	48	34	0.0198	=D16+E13	uw	0		
17	(Ra-226)td	20				vo	0		
18	(Ra-226)us	38				heo	1	1	0.8
19	(Ra-226)bd	20	35	0	=D19+E16	uw			
20	(Ra-226)b	1.9				vo			
21						heo			
22	ILCRocc.a	=IF(B25<0.0066,M5,IF(B25<0.0264,M18,IF(B25<0.2564,M25,IF(B25<0.5864,M28,IF(B25<0.9364,M37,IF(B25<0.9846,M43,IF(B25<0.9912,M66,M59))))))	43	0	=D22+E19	uw			
23	ILCRocc.b	=IF(B25<0.9846,0,IF(B25>0.9912,M66,M59))				vo			
24	ILCRocc	=B22+B23				heo			
25	RANDOM	=RAND()	44	0.23	=D25+E22	uw	1	1	1
26						vo	0		
27						heo	0		
28			45	0.33	=D28+E25	uw	1	1	1
29						vo	0		
30						heo	0		
31			46	0	=D31+E28	uw			
32						vo			
33						heo			
34			53	0	=D34+E31	uw			
35						vo			
36						heo			
37			54	0.37	=D37+E34	uw	0.95	1	1
38						vo	0		
39						heo	0.05	1	0.8
40			55	0	=D40+E37	uw			
41						vo			
42						heo			
43			56	0	=D43+E40	uw			
44						vo			
45						heo			
46			63	0	=D46+E43	uw			
47						vo			
48						heo			
49			64	0.0165	=D49+E46	uw	0		
50						vo	0		
51						heo	1	1	0.8
52			65	0.0132	=D52+E49	uw	0		
53						vo	0		
54						heo	1	1	0.8
55			66	0	=D55+E52	uw			
56						vo			
57						heo			
58			73	0.0066	=D58+E55	uw	0		
59						vo	1	1	0.8
60						heo	0		
61			74	0	=D61+E58	uw			
62						vo			
63						heo			
64			75	0.0066	=D64+E61	uw	0		
65						vo	0		
66						heo	1	1	0.8
67			76	0	=D67+E64	uw			
68						vo			
69						heo			
70			77	0	=D70+E67	uw			
71						vo			
72						heo			
73			=COUNT(C4:C72)		=SUM(D4:D72)				

	J	K	L	M	N	O
1						
2						
3	[Ra-226]soil,g	[Ra-226]g	Grid- and Job-Specific Dose Factor	ILCRocc,g	Weighted ILCRocc,g	Job
4					=M5*D4	uw
5	2.4	=J5	=((K5*I5)-\$B\$20)*H5	=IF(L5*\$B\$10<0.0,L5*\$B\$10)		vo
6						hoo
7					0	
8						
9					0	
10						
11					0	
12						
13					0	
14						
15					=M18*D16	
16						
17						
18		=B16	=((K18*I18)-\$B\$20)*H18	=IF(L18*\$B\$10<0.0,L18*\$B\$10)	0	
19						
20						
21					0	
22						
23						
24						
25		=IF(B25<0.7,B16,B15)	=((K25*I25)-\$B\$20)*H25	=IF(L25*\$B\$10<0.0,L25*\$B\$10)	=M25*D25	
26						
27						
28	3.7	=J28	=((K28*I28)-\$B\$20)*H28	=IF(L28*\$B\$10<0.0,L28*\$B\$10)	=M28*D28	
29						
30					0	
31						
32						
33					0	
34						
35						
36						
37		=IF(B25<0.9,B15,B11)	=((K37*I37)-\$B\$20)*H37	=IF(L37*\$B\$10<0.0,L37*\$B\$10)	=IF(B25<0.95,M37,M39)*D37	
38						
39		=K37	=((K39*I39)-\$B\$20)*H39	=IF(L39*\$B\$10<0.0,L39*\$B\$10)		
40					0	
41						
42					0	
43						
44					0	
45						
46					0	
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49					=M51*D49	
50						
51		=IF(B25<0.2,B12,IF(B25<0.4,B15,IF(B25<0.7,B17,B18)))	=((K51*I51)-\$B\$20)*H51	=IF(L51*\$B\$10<0.0,L51*\$B\$10)		
52					=M54*D52	
53						
54		=IF(B25<0.2,B13,IF(B25<0.4,B14,IF(B25<0.5,B15,B18)))	=((K54*I54)-\$B\$20)*H54	=IF(L54*\$B\$10<0.0,L54*\$B\$10)		
55					0	
56						
57						
58					=M59*D58	
59	5.1	=J59	=((K59*I59)-\$B\$20)*H59	=IF(L59*\$B\$10<0.0,L59*\$B\$10)		
60					0	
61						
62						
63						
64					=M66*D64	
65						
66	5.1	=IF(B25<0.1,B15,IF(B25<0.2,J66,B18))	=((K66*I66)-\$B\$20)*H66	=IF(L66*\$B\$10<0.0,L66*\$B\$10)		
67					0	
68						
69						
70					0	
71						
72						
73						

	P
1	
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3	Weighted ILCRocc
4	=IF(B25<0.25,M25,IF(B25<0.62,M28,M37))*(D26+D28+(D37*G37))
5	=IF(B25<0.8,M5,M59)*(D4+D59)
6	=IF(B25<0.26,M18,IF(B25<0.51,M39,IF(B25<0.73,M51,IF(B25<0.91,M54,M66))))*(D16+(D37*G39)+D49+D52+D
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Appendix G



MONTGOMERY WATSON

Appendix G

Grid-Specific Results for the Occupational Cancer Risk Model

**Occupational Scenario for Monsanto's Soda Springs Plant
Location-Specific Contribution Analysis**

Grid	Pr,g	Weighted ILCR _{occ,g,0.50}	Grid Contribution
23	0.0066	0	0%
24	0	0	0%
25	0	0	0%
33	0	0	0%
34	0.0198	5.8E-07	16.6%
35	0	0	0%
43	0	0	0%
44	0.23	2.9E-07	8.3%
45	0.33	1.03E-08	0.29%
46	0	0	0%
53	0	0	0%
54	0.37	2.0E-06	57%
55	0	0	0%
56	0	0	0%
63	0	0	0%
64	0.0165	2.6E-07	7.4%
65	0.0132	2.4E-07	6.9%
66	0	0	0%
73	0.0066	1.52E-08	0.43%
74	0	0	0%
75	0.0066	1.03E-07	2.9%
76	0	0	0%
77	0	0	0%
Sum	1.00	3.5E-06	100%

Appendix H



MONTGOMERY WATSON

Appendix H

Job-Specific Results for the Occupational Cancer Risk Model

**Occupational Scenario for Monsanto's Soda Springs Plant
Job-Specific Contribution Analysis**

Job Category	P _j	Weighted ILCR _{occ,j,0.50}	Job Contribution
uw	0.91	4.3E-07	24%
vo	0.0132	2.2E-09	0.123%
heo	0.077	1.36E-06	76%
Sum	1.00	1.79E-06	100%

Appendix I



MONTGOMERY WATSON

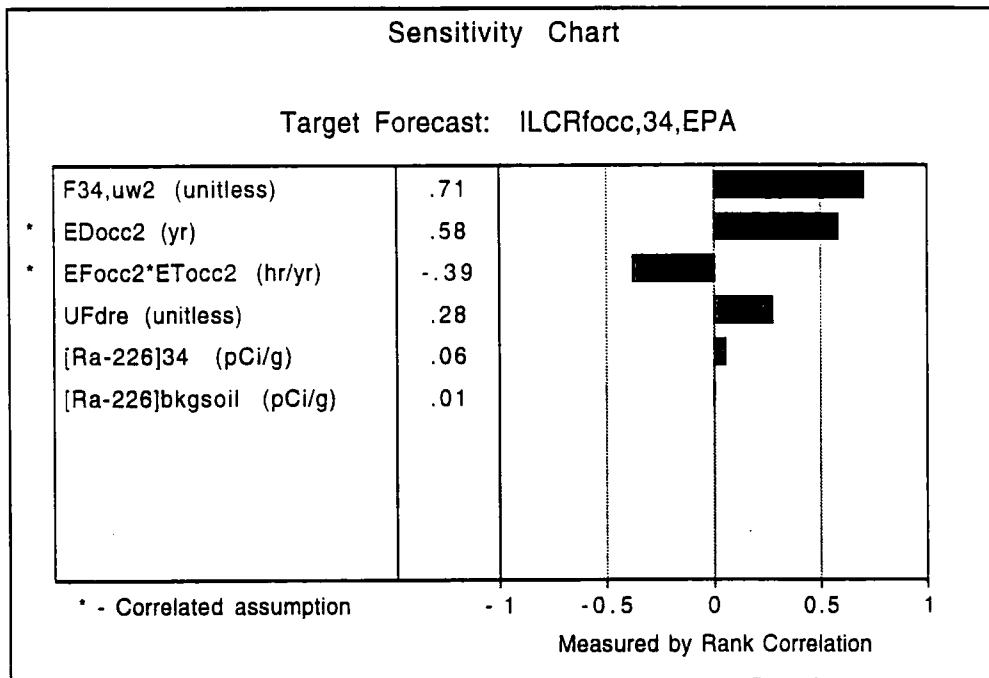
Appendix I

Crystal Ball® Report—EPA's Perspective on a Future Occupational Cancer Risk Model

Crystal Ball Report:
**EPA's Perspective on the Future Occupational Subscenario for Monsanto's
Soda Springs Plant for a Subpopulation of Workers on the Slag Pile**

Simulation started on Mon, Feb 12, 1996 at 16:32:14

Simulation stopped on Mon, Feb 12, 1996 at 16:40:54

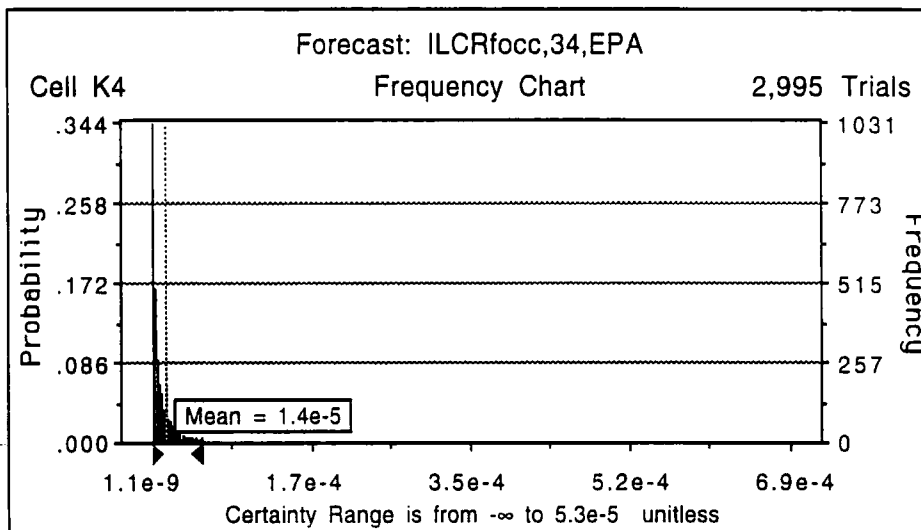


Sum of r-squared values = 1.07

Forecast: ILCRfocc,34,EPA

Cell: K4

Statistics:	Value
Trials	2,995
Mean	1.43E-05
Median	4.4E-06
Standard deviation	3.7E-05
Variance	1.36E-09
Coefficient of variation	2.6



Forecast: ILCRfocc,34,EPA (cont'd)

Cell: K4

<u>Percentile</u>	<u>ILCRfocc,34,EPA</u>
0.03%	1.13E-09
5.00%	1.88E-07
10.00%	4.2E-07
15.00%	7.0E-07
20.00%	1.01E-06
25.00%	1.38E-06
30.00%	1.80E-06
35.00%	2.4E-06
40.00%	2.9E-06
45.00%	3.6E-06
50.00%	4.4E-06
55.00%	5.5E-06
60.00%	6.9E-06
65.00%	8.5E-06
70.00%	1.08E-05
75.00%	1.32E-05
80.00%	1.78E-05
85.00%	2.3E-05
90.00%	3.2E-05
95.00%	5.3E-05
98.00%	9.9E-05
99.00%	1.53E-04
99.90%	5.5E-04
99.97%	6.9E-04
> 99.97% (Point estimate)	2E-03

End of Forecast

Assumptions

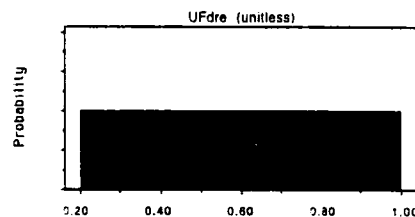
Assumption: UFdre (unitless)

Cell: B4

Uniform distribution with parameters:

Minimum	0.20
Maximum	1.00

Mean value in simulation was 0.60



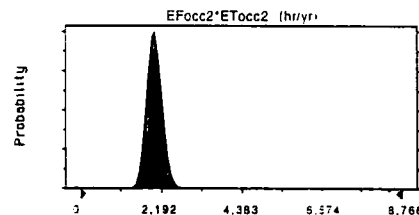
Assumption: EFocc2*ETocc2 (hr/yr)

Cell: B6

Beta distribution with parameters:

Alpha	77
Beta	260
Scale	8,766

Selected range is from 0 to 8,766
Mean value in simulation was 2,000



Correlated with:

EDocc2 (yr) (B7)	-0.71
------------------	-------

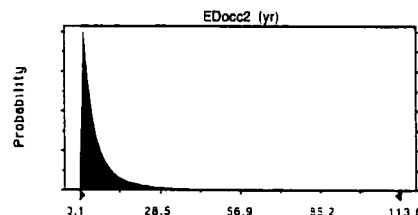
Assumption: EDocc2 (yr)

Cell: B7

Lognormal distribution with parameters:

Mean	7.4
Std. deviation	11.7

Selected range is from 0 to ∞
Mean value in simulation was 7.3



Correlated with:

EFocc2*ETocc2 (hr/yr) (B6)	-0.71
----------------------------	-------

Assumption: [Ra-226]bkgsoil (pCi/g)

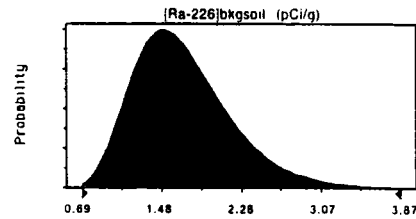
Cell: B11

Lognormal distribution with parameters:

Mean	1.70
Std. deviation	0.50

Selected range is from 0 to ∞

Mean value in simulation was 1.69



Assumption: F34,uw2 (unitless)

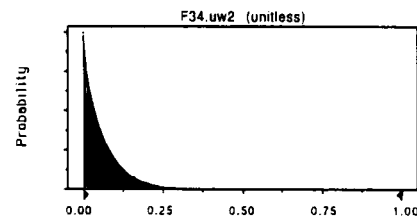
Cell: F4

Beta distribution with parameters:

Alpha	0.93
Beta	14.0
Scale	1.00

Selected range is from 0 to 1.00

Mean value in simulation was 0.060



Assumption: [Ra-226]34 (pCi/g)

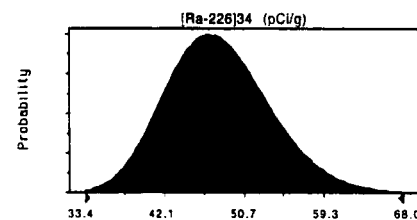
Cell: H4

Lognormal distribution with parameters:

Mean	48
Std. deviation	5.7

Selected range is from 0 to ∞

Mean value in simulation was 48



End of Assumptions

[illegible]

Appendix J



MONTGOMERY WATSON

Appendix J

Comparison of Two Versions of Residential Cancer Risk Models

Residential Cancer Risk Models for Monsanto Company's Elemental Phosphorus Plant Soda Springs, Idaho

The following is a comparison of two versions of residential cancer risk models for the Monsanto Soda Springs Plant. In actuality, two types of models are compared.

The model for the current residential situation has been simplified to focus only on arsenic ingestion exposures, as preliminary work performed by Science Applications International Corporation has demonstrated that this is the dominant constituent-pathway element with respect to the overall risk estimate obtained with a deterministic multiple constituent-pathway model. For the future residential situation, the focus is on external gamma radiation exposures attributable to radium-226, as SAIC's preliminary work has demonstrated that this is the only constituent-pathway element, of the multiple constituent-pathway deterministic model, that contributes significantly to the overall risk estimate for the future residential scenario.

Version 1—United States Environmental Protection Agency, Region 10, and, Science Applications International Corporation

Arsenic Ingestion Model

$$ILCR_{\text{cres}} = \frac{SF_{As} \times IngR_{s/d} \times EF_{\text{res}} \times ED_{\text{res}} \times ([As] - [As]_b) \times UCF_m}{BW \times AT \times UCF_{t2}}$$

Each of the arsenic model variables and invariate parameters are defined below:

- $ILCR_{\text{cres}}$: current incremental lifetime cancer rate which is attributable to ingestion of soil containing elevated levels of arsenic (unitless).
- SF_{As} : cancer potency slope factor for ingestion of arsenic (kg-d/mg).
- $IngR_{s/d}$: ingestion rate of soil and dust (mg/d).
- EF_{res} : exposure frequency (d/yr).
- ED_{res} : exposure duration (yr).
- $[As]$: grid-specific concentration of arsenic in soil (mg/kg).
- $[As]_b$: background concentration of arsenic in soil (mg/kg).
- UCF_m : mass unit conversion factor (kg/mg).
- BW : body weight (kg).
- AT : averaging time (*i.e.*, an average lifespan) (yr).
- UCF_{t2} : time unit conversion factor #2 (d/yr).

Radium-226 External Gamma Exposure Model

$$ILCR_{fres} = \frac{SF_{Ra,res} \times EF_{res} \times ED_{res} \times \left([^{226}Ra] \times DRF \right) - [^{226}Ra]_b}{UCF_{t1} \times UCF_{t2}}$$

Each of the radium model variables and invariate parameters are defined below:

- $ILCR_{fres}$: future incremental lifetime cancer rate attributable to external gamma radiation emitted from elevated levels of radium-226 in soil (unitless).
- $SF_{Ra,res}$: cancer potency slope factor for general population exposures to external gamma radiation derived from radium-226 [g/(pCi·yr)].
- EF_{res} : exposure frequency (*i.e.*, days of exposure per year).
- ED_{res} : exposure duration (yr).
- $[^{226}Ra]$: concentration of radium-226 in soil near the assumed point of residency (pCi/g).
- DRF : dose-reduction factor (*i.e.*, shielding factor for gamma radiation) (unitless).
- $[^{226}Ra]_b$: background concentration of radium-226 in soil (pCi/g).
- UCF_{t1} : time unit conversion factor #1 (hr/d).
- UCF_{t2} : time unit conversion factor #2 (d/yr).

Version 2—Monsanto Company and Montgomery Watson

Arsenic Ingestion Model

$$ILCR_{cres,g} = \frac{SF_{As} \times IngR_{s/d} \times EF_{res} \times ED_{res} \times ([As]_g - [As]_b) \times BF_{s,As} \times F_s \times F_1 \times UCF_m}{BW \times BF_{w,As} \times AT \times UCF_{t2}}$$

Each of the arsenic model variables and invariate parameters are defined below:

- $ILCR_{cres,g}$: current incremental lifetime cancer rate, within a specific grid, which is attributable to ingestion of soil containing elevated levels of arsenic (unitless).
- SF_{As} : cancer potency slope factor for ingestion of arsenic (kg·d/mg).
- $IngR_{s/d}$: ingestion rate of soil and dust (mg/d).

- EF_{res} : residential exposure frequency (d/yr).
- ED_{res} : residential exposure duration (yr).
- $[As]_g$: grid-specific concentration of arsenic in soil (mg/kg).
- $[As]_b$: background concentration of arsenic in soil (mg/kg).
- $BF_{s,As}$: bioavailability factor of arsenic in soil (unitless).
- F_s : fraction of soil and dust consumed that is soil (unitless).
- F_l : fraction of time spent locally (unitless).
- UCF_m : mass unit conversion factor (kg/mg).
- BW: body weight (kg).
- $BF_{w,As}$: bioavailability factor of arsenic in water (unitless).
- AT: averaging time (*i.e.*, an average lifespan) (yr).
- UCF_{t2} : time unit conversion factor #2 (d/yr).

Radium-226 External Gamma Exposure Model

$$ILCR_{fres,g} = \frac{SF_{Ra,res} \times EF_{res} \times ED_{res} \times \left[([^{226}Ra]_g \times TSGF \times DRF) - [^{226}Ra]_b \right] \times F_o \times F_l}{UCF_{t2}} \times UF_{dre}$$

Each of the radium model variables and invariate parameters are defined below:

- $ILCR_{fres,g}$: future incremental lifetime cancer rate, within a specific grid, which is attributable to external gamma radiation emitted from elevated levels of radium-226 in soil (unitless).
- $SF_{Ra,res}$: cancer potency slope factor for general population exposures to external gamma radiation derived from radium-226 [g/(pCi·yr)].
- EF_{res} : residential exposure frequency (d/yr).
- ED_{res} : residential exposure duration (yr).
- $[^{226}Ra]_g$: grid-specific concentration of radium-226 in soil (pCi/g).
- DRF: dose-reduction factor (*i.e.*, shielding factor for gamma radiation) (unitless).

- TSGF: thin-shell geometry factor (*i.e.*, factor to account for the fact that the elevated ^{226}Ra is confined to the upper portion of the soil column).
- $[^{226}\text{Ra}]_b$: background concentration of radium-226 in soil (pCi/g).
- F_o : fraction of the time spent outdoors (unitless).
- F_l : fraction of outdoor time that is spent locally (unitless).
- UCF_{12} : time unit conversion factor #2 (d/yr).
- UF_{dre} : uncertainty factor for dose-rate effectiveness associated with high-dose-to-low-dose and instantaneous-dose-to-protracted-dose extrapolations (unitless).

For both the arsenic and radium models, to estimate the risk for an individual selected at random from the residential population, ILCR_{res} , each $\text{ILCR}_{\text{res},g}$ is sampled randomly in weighted fashion where the weighting factor is $P_{r,g}$, the proportion of the residential population within the near vicinity of the plant located within a specific grid ($\sum_g P_{r,g} = 1.00$).

Summary

The two sets of models have the same general structures. The second versions were developed for use in a stochastic analysis, as opposed to the deterministic analysis used with the first versions. Other refinements associated with the second versions include:

Arsenic Ingestion Model

- $[\text{As}]$ is from all occupied portions of the site vicinity, not just from an assumed points of residency.
- $\text{BF}_{s,\text{As}}$ accounts for the fact that arsenic in soil is not highly absorbed when ingested.
- $\text{BF}_{w,\text{As}}$ accounts for the fact that arsenic ingested in water (the exposure route upon which SF_{As} data are derived) is less than completely absorbed.
- F_s accounts for the fact that all dirt ingested is not derived from soil.
- F_l accounts for the fact that one typically does not spend all of one's time at home.

Radium-226 External Gamma Exposure Model

- $[^{226}\text{Ra}]$ is from all occupied portions of the site vicinity, not just from a single assumed point of residency.

- TSGF is added to account for the fact that the elevated levels of ^{226}Ra are not infinitely thick, but confined to a thin surface layer.
- UF_{dre} is added to account for uncertainty in using high-dose and instantaneous-dose radiation data to predict effects at the very low, protracted, and fractionated doses of radiation experienced by people residing in the vicinity of the site (this variable is not used in the arsenic model as naturally occurring, albeit elevated, levels of arsenic have been associated with cancer; whereas protracted, fractionated, low-level radiation effects are extrapolated from unnaturally high, short-term—*e.g.*, atomic detonation, medical irradiation—exposures; in short, there is uncertainty associated with the arsenic extrapolations, but they are no where as large as those associated with the radiation extrapolations).

For both the arsenic and radium models, ILCR_{res} is specific to the entire population of residents in the vicinity of the plant, as opposed to a hypothetical resident of a narrow subpopulation.

Appendix K



MONTGOMERY WATSON

Appendix K

Kriging Results for Arsenic Concentrations in Surface Soil

Grid-Specific Statistics for Arsenic Surface Soil Concentrations On and Near the Monsanto Soda Springs Plant		
Grid	Mean	[As]g (mg/kg)* Standard Deviation
1	5.0	3.4
2	3.9	1.54
3	4.1	1.46
4	4.8	1.80
5	4.1	1.90
6	2.7	1.37
7	2.2	0.88
8	2.3	1.29
9	2.6	1.89
11	4.3	2.9
12	4.1	1.90
13	5.0	1.90
14	6.6	2.1
15	4.9	1.75
16	1.85	0.74
17	1.16	0.38
18	1.63	0.58
19	2.2	1.23
21	4.3	3.0
22	4.2	2.0
23	5.1	1.27
24	7.2	1.79
25	5.5	1.83
26	2.8	0.91
27	1.39	0.59
28	1.62	0.78
29	1.94	0.98
31	3.9	2.7
32	4.4	2.2
33	5.4	1.81
34	6.6	2.9
35	5.3	1.97
36	3.0	1.12
37	2.0	0.88
38	2.1	1.13
39	2.1	0.93
41	3.3	1.95
42	4.4	2.2
43	6.0	2.3
44	6.6	3.3
45	5.3	2.3
46	3.7	1.52
47	3.0	1.61
48	2.9	1.70
49	3.0	1.73
51	2.6	1.03
52	4.2	1.82
53	7.3	3.0
54	8.4	4.3
55	7.0	3.3
56	5.0	2.1
57	3.9	2.0
58	3.5	1.76
59	4.1	2.0
61	3.0	1.45
62	4.9	2.0
63	8.7	2.7
64	11.4	5.2
65	10.4	4.6
66	6.7	2.2
67	4.8	2.1
68	3.7	1.29
69	4.6	1.91
71	3.4	1.26
72	5.7	2.0
73	9.1	2.4
74	14.7	4.0
75	16.1	4.3
76	7.2	1.93
77	6.3	2.2
78	4.8	1.96
79	4.0	1.72
81	5.2	2.3
82	7.9	2.5
83	10.7	4.2
84	14.2	5.5
85	15.2	4.4
86	10.0	3.9
87	8.6	2.8
88	4.8	1.56
89	3.5	1.37
background	4.0	0.85

*Grid-specific concentrations of arsenic in surface soil.

Appendix L



MONTGOMERY WATSON

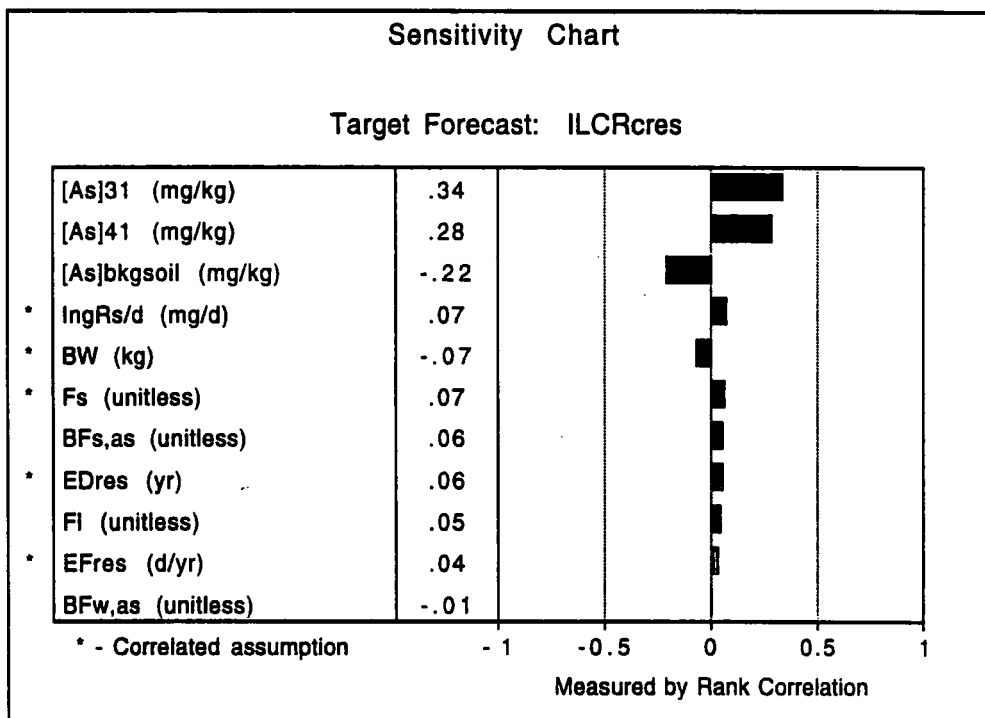
Appendix L

Crystal Ball® Report—Current Residential Cancer Risk Model

Crystal Ball Report:
Current Residential Subscenario for Monsanto's Soda Springs Plant

Simulation started on Sat, Feb 24, 1996 at 14:33:53

Simulation stopped on Sat, Feb 24, 1996 at 14:40:17

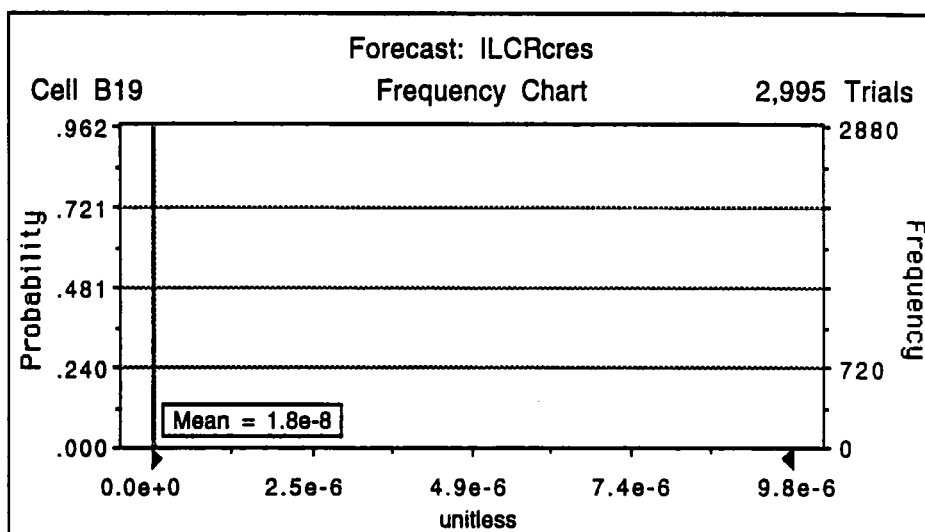


Sum of r-squared values = 0.27

Forecast: ILCRcres

Cell: B19

Statistics:	Value
Trials	2,995
Mean	1.80E-08
Median	0
Standard deviation	2.3E-07
Variance	5.5E-14
Coefficient of variation	13.0



Forecast: ILCRcres (cont'd)

Cell: B19

<u>Percentile</u>	<u>ILCRcres</u>
0.03%	0
5.00%	0
10.00%	0
15.00%	0
20.00%	0
25.00%	0
30.00%	0
35.00%	0
40.00%	0
45.00%	0
50.00%	0
55.00%	0
60.00%	0
65.00% (Point estimate for western area)	0
70.00%	4.5E-12
75.00%	7.1E-11
80.00%	3.8E-10
85.00%	1.22E-09
90.00%	4.6E-09
95.00%	2.0E-08
98.00%	1.13E-07
99.00%	2.8E-07
99.90%	2.9E-06
99.97%	9.8E-06

End of Forecast

Assumptions

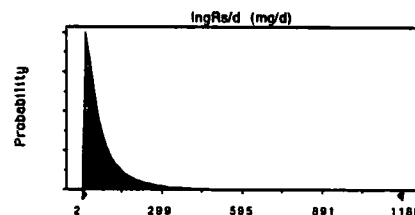
Assumption: IngRs/d (mg/d)

Cell: B5

Lognormal distribution with parameters:

Mean	91
Std. deviation	126

Selected range is from 0 to ∞
 Mean value in simulation was 94



Correlated with:

BW (kg) (B12)	-0.71
Fs (unitless) (B6)	0.71

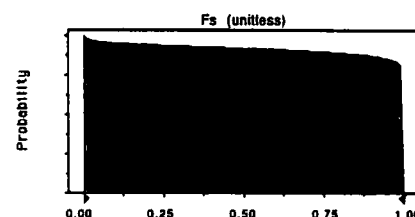
Assumption: Fs (unitless)

Cell: B6

Beta distribution with parameters:

Alpha	0.99
Beta	1.03
Scale	1.00

Selected range is from 0 to 1.00
 Mean value in simulation was 0.49



Correlated with:

IngRs/d (mg/d) (B5)	0.71
---------------------	------

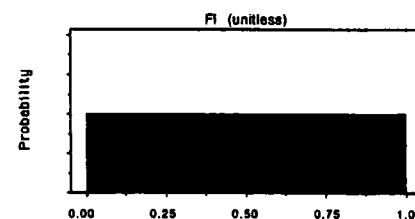
Assumption: FI (unitless)

Cell: B7

Uniform distribution with parameters:

Minimum	0
Maximum	1.00

Mean value in simulation was 0.50



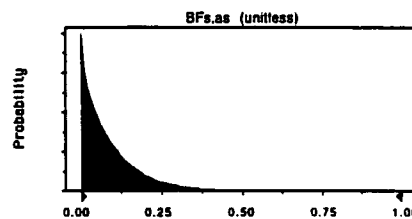
Assumption: BFs,as (unitless)**Cell: B8**

Beta distribution with parameters:

Alpha	0.91
Beta	9.2
Scale	1.00

Selected range is from 0 to 1.00

Mean value in simulation was 0.095

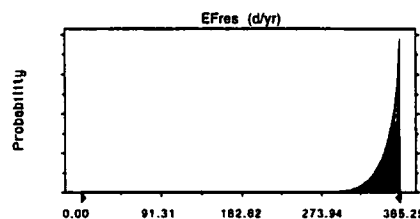
**Assumption: EFres (d/yr)****Cell: B9**

Beta distribution with parameters:

Alpha	21
Beta	0.92
Scale	365.25

Selected range is from 0 to 365.25

Mean value in simulation was 350



Correlated with:

BW (kg) (B12)	-0.50
---------------	-------

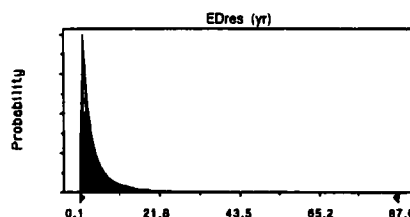
Assumption: EDres (yr)**Cell: B10**

Lognormal distribution with parameters:

Mean	4.6
Std. deviation	8.7

Selected range is from 0 to ∞

Mean value in simulation was 4.6



Correlated with:

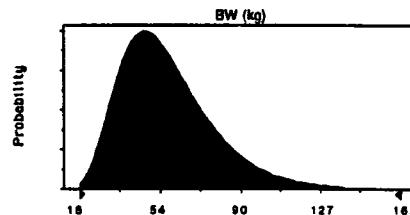
BW (kg) (B12)	-0.50
---------------	-------

Assumption: BW (kg)**Cell: B12**

Lognormal distribution with parameters:

Mean	58
Std. deviation	22

Selected range is from 0 to ∞
Mean value in simulation was 58



Correlated with:

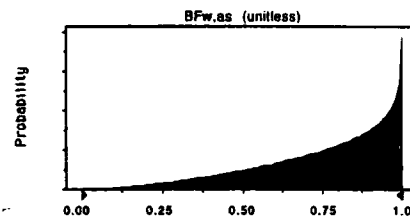
IngRs/d (mg/d) (B5)	-0.71
EFres (d/yr) (B9)	-0.50
EDres (yr) (B10)	-0.50

Assumption: BFW,as (unitless)**Cell: B13**

Beta distribution with parameters:

Alpha	2.4
Beta	0.81
Scale	1.00

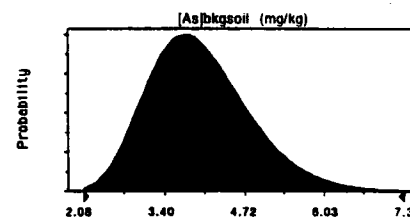
Selected range is from 0 to 1.00
Mean value in simulation was 0.74

**Assumption: [As]bkgsoil (mg/kg)****Cell: B17**

Lognormal distribution with parameters:

Mean	4.0
Std. deviation	0.85

Selected range is from 0 to ∞
Mean value in simulation was 4.0



Assumption: [As]31 (mg/kg)**Cell: F31**

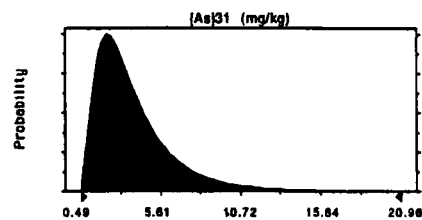
Lognormal distribution with parameters:

Mean 3.9

Std. deviation 2.7

Selected range is from 0 to ∞

Mean value in simulation was 3.8

**Assumption: [As]41 (mg/kg)****Cell: F40**

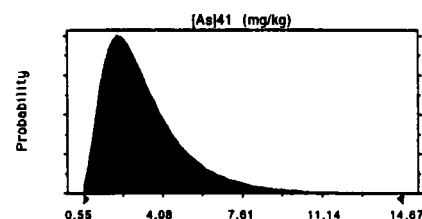
Lognormal distribution with parameters:

Mean 3.3

Std. deviation 1.95

Selected range is from 0 to ∞

Mean value in simulation was 3.4

**End of Assumptions**

	A	B	C	D	E	F	G	H	I
1	Current Residential Cancer Risk Model								
2	Montanto Company/Montgomery Watson								
3	Common Dose & Toxicity Factor	Grid	Pr.g	Cumulative Pr.g	(As)b	Incremental (As)b	ILCRres.g	Weighted ILCRres.g	
4	SFes	1.75	1	0			0		
5	IngRs/d	1.00	2	0			0		
6	Ps	1.00	3	0			0		
7	FI	1.00	4	0			0		
8	BFs,as	1.00	5	0			0		
9	EFres	350.00	6	0			0		
10	EDres	30.0	7	0			0		
11	UCFm	1.00E-06	8	0			0		
12	BW	55	9	0			0		
13	BFw,as	1.00	11	0			0		
14	AT	70	12	0			0		
15	UCFI2	365.25	13	0			0		
16	Common Dose & Toxicity Factor	1.2E-06	14	0			0		
17	(As)b	4.00	15	0			0		
18			16	0			0		
19	ILCRres	0.0E+00	17	0			0		
20	RANDOM	0.26	18	0			0		
21			19	0			0		
22			21	0			0		
23			22	0			0		
24			23	0			0		
25			24	0			0		
26			25	0			0		
27			26	0			0		
28			27	0			0		
29			28	0			0		
30			29	0			0		
31			31	0.50	0.50	-3.90	-0.10	0.0E+00	0.0E+00
32			32	0			0		
33			33	0			0		
34			34	0			0		
35			35	0			0		
36			36	0			0		
37			37	0			0		
38			38	0			0		
39			39	0			0		
40			41	0.50	1.00	-3.90	-0.70	0.0E+00	0.0E+00
41			42	0			0		
42			43	0			0		
43			44	0			0		
44			45	0			0		
45			46	0			0		
46			47	0			0		
47			48	0			0		
48			49	0			0		
49			51	0			0		
50			52	0			0		
51			53	0			0		
52			54	0			0		
53			55	0			0		
54			56	0			0		
55			57	0			0		
56			58	0			0		
57			59	0			0		
58			61	0			0		
59			62	0			0		
60			63	0			0		
61			64	0			0		
62			65	0			0		
63			66	0			0		
64			67	0			0		
65			68	0			0		
66			69	0			0		
67			71	0			0		
68			72	0			0		
69			73	0			0		
70			74	0			0		
71			75	0			0		
72			76	0			0		
73			77	0			0		
74			78	0			0		
75			79	0			0		
76			81	0			0		
77			82	0			0		
78			83	0			0		
79			84	0			0		
80			85	0			0		
81			86	0			0		
82			87	0			0		
83			88	0			0		
84			89	0			0		
85			81	1.00					

	A	B	C	D	E	F	G
1	Current Residential Cancer Risk Model						
2	Montana Company/Idaho Company/Watson						
3	Common Dose & Toxicity Factors		Grid	Pr.g	Cumulative Pr.g	Incremental (As)g	
4	SPas	1.75	1	0			
5	IngRs/d	100	2	0			
6	Rs	1	3	0			
7	FI	1	4	0			
8	BFs.as	1	5	0			
9	EFres	300	6	0			
10	EDres	30	7	0			
11	UCFm	0.000001	8	0			
12	BW	65	9	0			
13	BFw.as	1	11	0			
14	AT	70	12	0			
15	UCF2	365.25	13	0			
16	Common Dose & Toxicity Factor	=B4*B5*B6*B7*B8*B9*B10*B11/(B12*B13*B14*B15)	14	0			
17	(As)b	4	15	0			
18			16	0			
19	ILCRres	=IF(B20-E31,H31,H40)	17	0			
20	RANDOM	=RAND()	18	0			
21			19	0			
22			21	0			
23			22	0			
24			23	0			
25			24	0			
26			25	0			
27			26	0			
28			27	0			
29			28	0			
30			29	0			
31			31	0.5	=D31+E30	3.0	=F31-\$B\$17
32			32	0			
33			33	0			
34			34	0			
35			35	0			
36			36	0			
37			37	0			
38			38	0			
39			39	0			
40			41	0.5	=D40+E39	3.0	=F40-\$B\$17
41			42	0			
42			43	0			
43			44	0			
44			45	0			
45			46	0			
46			47	0			
47			48	0			
48			49	0			
49			51	0			
50			52	0			
51			53	0			
52			54	0			
53			55	0			
54			56	0			
55			57	0			
56			58	0			
57			59	0			
58			61	0			
59			62	0			
60			63	0			
61			64	0			
62			65	0			
63			66	0			
64			67	0			
65			68	0			
66			69	0			
67			71	0			
68			72	0			
69			73	0			
70			74	0			
71			75	0			
72			76	0			
73			77	0			
74			78	0			
75			79	0			
76			81	0			
77			82	0			
78			83	0			
79			84	0			
80			85	0			
81			86	0			
82			87	0			
83			88	0			
84			89	0			
85			81	=SUM(D4:D84)			

	H	I
1		
2		
3	ILCRres.g	Weighted ILCRres.g
4	0	
5	0	
6	0	
7	0	
8	0	
9	0	
10	0	
11	0	
12	0	
13	0	
14	0	
15	0	
16	0	
17	0	
18	0	
19	0	
20	0	
21	0	
22	0	
23	0	
24	0	
25	0	
26	0	
27	0	
28	0	
29	0	
30	0	
31	=IF(\$B\$16*G31<0.0,\$B\$16*G31)	=H31*D31
32	0	
33	0	
34	0	
35	0	
36	0	
37	0	
38	0	
39	0	
40	=IF(\$B\$16*G40<0.0,\$B\$16*G40)	=H40*D40
41	0	
42	0	
43	0	
44	0	
45	0	
46	0	
47	0	
48	0	
49	0	
50	0	
51	0	
52	0	
53	0	
54	0	
55	0	
56	0	
57	0	
58	0	
59	0	
60	0	
61	0	
62	0	
63	0	
64	0	
65	0	
66	0	
67	0	
68	0	
69	0	
70	0	
71	0	
72	0	
73	0	
74	0	
75	0	
76	0	
77	0	
78	0	
79	0	
80	0	
81	0	
82	0	
83	0	
84	0	
85		

Appendix M



MONTGOMERY WATSON

Appendix M

Grid-Specific Results for the Current Residential Cancer Risk Model

**Current Residential Subscenario for Monsanto's Soda Springs Plant
Location-Specific Contribution Analysis**

Grid	Pr,g	Weighted ILCR _{cres,g,0.50}	Grid Contribution
31	0.50	0	50%
41	0.50	0	50%
Sum	1.00	0	100%

Appendix N



MONTGOMERY WATSON

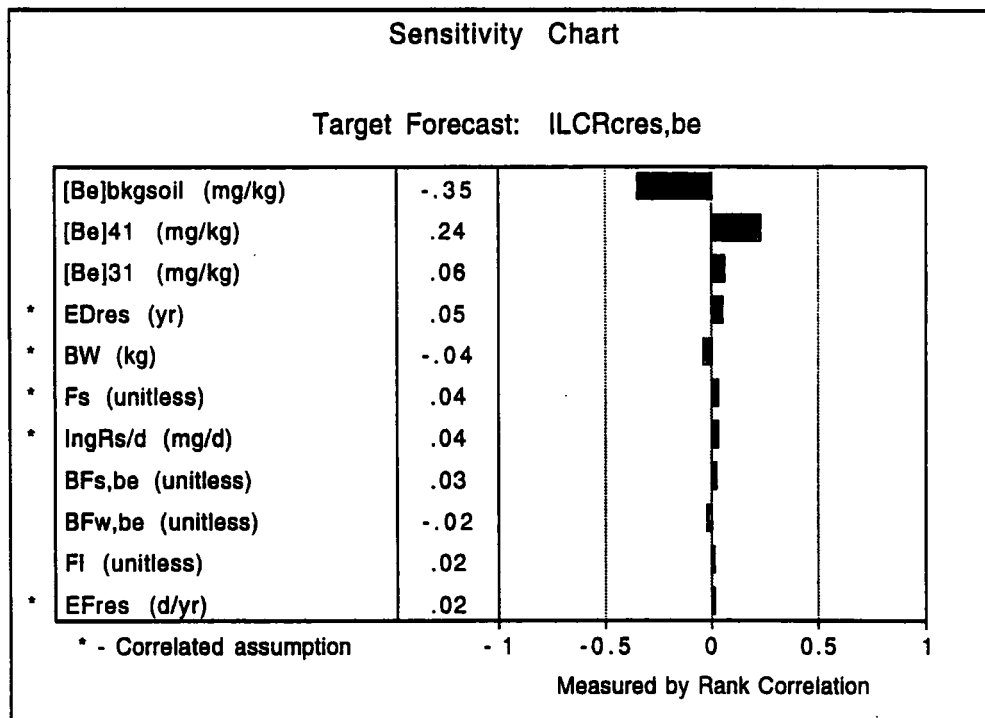
Appendix N

**Crystal Ball® Report—Current Residential Cancer Risk Model (Beryllium Ingestion
Version)**

Crystal Ball Report:
Current Residential Subscenario for Beryllium Ingestion
for Monsanto's Soda Springs Plant

Simulation started on Sat, Feb 24, 1996 at 13:20:08

Simulation stopped on Sat, Feb 24, 1996 at 13:26:01

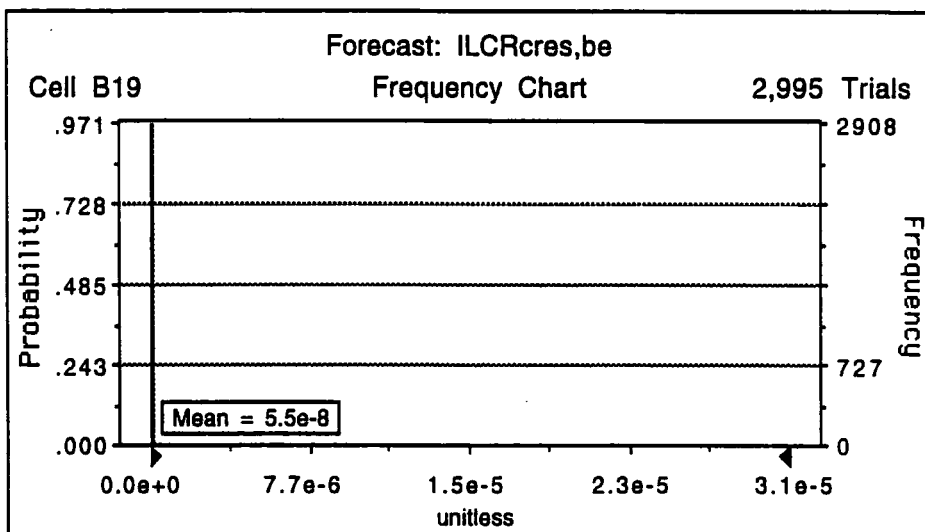


Sum of r-squared values = 0.194

Forecast: ILCR_{cres,be}

Cell: B19

Statistics:	Value
Trials	2995
Mean	5.5E-08
Median	0
Standard deviation	8.4E-07
Variance	7.1E-13
Coefficient of variation	15.3



Forecast: ILCR_{cres,be} (cont'd)

Cell: B19

<u>Percentile</u>	<u>ILCR_{cres,be}</u>
0.03%	0
5.00%	0
10.00%	0
15.00%	0
20.00%	0
25.00%	0
30.00%	0
35.00%	0
40.00%	0
45.00%	0
50.00%	0
55.00%	0
60.00%	0
65.00%	0
70.00%	0
75.00%	0
80.00%	2.2E-11
85.00%	6.3E-10
90.00%	5.2E-09
95.00%	4.1E-08
98.00%	2.4E-07
99.00%	6.5E-07
99.53% (Point estimate for western area)	2E-06
99.90%	1.29E-05
99.97%	3.1E-05

End of Forecast

Assumptions

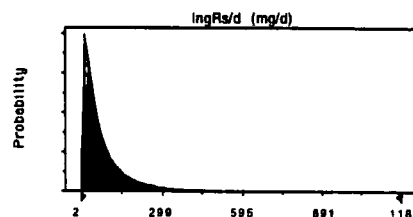
Assumption: IngRs/d (mg/d)

Cell: B5

Lognormal distribution with parameters:

Mean	91
Std. deviation	126

Selected range is from 0 to ∞
Mean value in simulation was 89



Correlated with:

Fs (unitless) (B6)	0.71
BW (kg) (B12)	-0.71

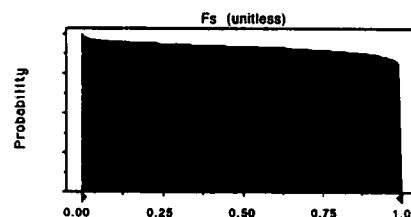
Assumption: Fs (unitless)

Cell: B6

Beta distribution with parameters:

Alpha	0.99
Beta	1.03
Scale	1.00

Selected range is from 0 to 1.00
Mean value in simulation was 0.50



Correlated with:

IngRs/d (mg/d) (B5)	0.71
---------------------	------

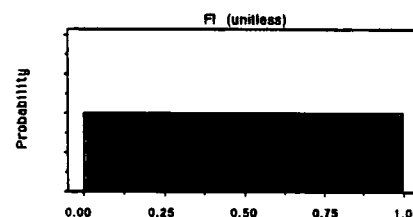
Assumption: FI (unitless)

Cell: B7

Uniform distribution with parameters:

Minimum	0
Maximum	1.00

Mean value in simulation was 0.49



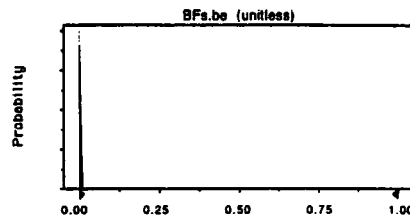
Assumption: BFs,be (unitless)

Cell: B8

Beta distribution with parameters:

Alpha	1.00
Beta	1,000
Scale	1.00

Selected range is from 0 to 1.00
Mean value in simulation was 0.00099



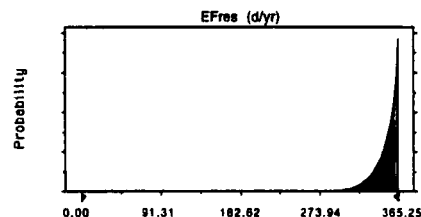
Assumption: EFres (d/yr)

Cell: B9

Beta distribution with parameters:

Alpha	21
Beta	0.92
Scale	365.25

Selected range is from 0 to 365.25
Mean value in simulation was 350



Correlated with:

BW (kg) (B12) -0.50

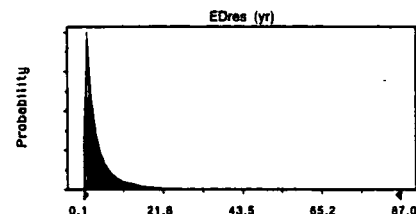
Assumption: EDres (yr)

Cell: B10

Lognormal distribution with parameters:

Mean	4.6
Std. deviation	8.7

Selected range is from 0 to ∞
Mean value in simulation was 4.3



Correlated with:

BW (kg) (B12) -0.50

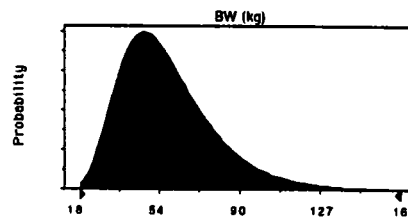
Assumption: BW (kg)

Cell: B12

Lognormal distribution with parameters:

Mean	58
Std. deviation	22

Selected range is from 0 to ∞
Mean value in simulation was 57



Correlated with:

EFres (d/yr) (B9)	-0.50
EDres (yr) (B10)	-0.50
IngRs/d (mg/d) (B5)	-0.71

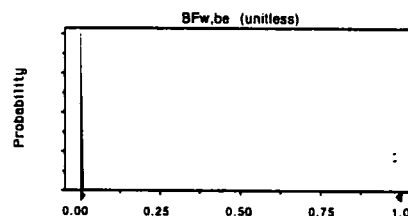
Assumption: BFw,be (unitless)

Cell: B13

Beta distribution with parameters:

Alpha	1.00
Beta	1,000
Scale	1.00

Selected range is from 0 to 1.00
Mean value in simulation was 0.00100



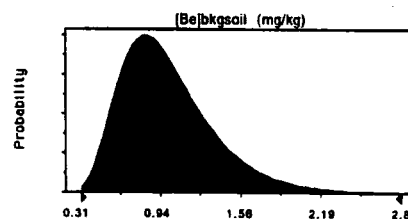
Assumption: [Be]bkgsoil (mg/kg)

Cell: B17

Lognormal distribution with parameters:

Mean	1.00
Std. deviation	0.38

Selected range is from 0 to ∞
Mean value in simulation was 1.00



Assumption: [Be]31 (mg/kg)

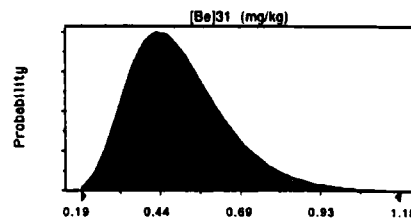
Cell: F31

Lognormal distribution with parameters:

Mean	0.50
Std. deviation	0.154

Selected range is from 0 to ∞

Mean value in simulation was 0.50



Assumption: [Be]41 (mg/kg)

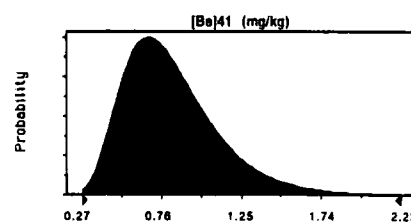
Cell: F40

Lognormal distribution with parameters:

Mean	0.82
Std. deviation	0.30

Selected range is from 0 to ∞

Mean value in simulation was 0.82



End of Assumptions

	A	B	C	D	E	F	G	H	I
1	Current Residential Cancer Risk Model — Be Ingestion								
2	Montgomery Watson								
3	Common Dose & Toxicity Factors	Grid	Pr	Cumulative Pr	g	Be	Incremental Be	ILCRres.be.g	ILCRres.be.g
4	SFbe	4.3	1	0				0	
5	IngRs/d	100	2	0				0	
6	Fa	1.00	3	0				0	
7	Fi	1.00	4	0				0	
8	BFs.be	1.00000	5	0				0	
9	EFres	350.00	6	0				0	
10	EDres	30.0	7	0				0	
11	UCFm	1.00E-06	8	0				0	
12	BW	50	9	0				0	
13	BFw.be	1.00000	11	0				0	
14	AT	70	12	0				0	
15	UCF12	365.25	13	0				0	
16	Common Dose & Toxicity Factor	3.0E-06	14	0				0	
17	BeIb	4.00	15	0				0	
18			16	0				0	
19	ILCRres.be	0.0E+00	17	0				0	
20	RANDOM	0.48	18	0				0	
21			19	0				0	
22			21	0				0	
23			22	0				0	
24			23	0				0	
25			24	0				0	
26			25	0				0	
27			26	0				0	
28			27	0				0	
29			28	0				0	
30			29	0				0	
31			31	0.50	0.50	-3.50	0.0E+00	0.0E+00	
32			32	0				0	
33			33	0				0	
34			34	0				0	
35			35	0				0	
36			36	0				0	
37			37	0				0	
38			38	0				0	
39			39	0				0	
40			41	0.50	1.00	-3.18	0.0E+00	0.0E+00	
41			42	0				0	
42			43	0				0	
43			44	0				0	
44			45	0				0	
45			46	0				0	
46			47	0				0	
47			48	0				0	
48			49	0				0	
49			51	0				0	
50			52	0				0	
51			53	0				0	
52			54	0				0	
53			55	0				0	
54			56	0				0	
55			57	0				0	
56			58	0				0	
57			59	0				0	
58			61	0				0	
59			62	0				0	
60			63	0				0	
61			64	0				0	
62			65	0				0	
63			66	0				0	
64			67	0				0	
65			68	0				0	
66			69	0				0	
67			71	0				0	
68			72	0				0	
69			73	0				0	
70			74	0				0	
71			75	0				0	
72			76	0				0	
73			77	0				0	
74			78	0				0	
75			79	0				0	
76			81	0				0	
77			82	0				0	
78			83	0				0	
79			84	0				0	
80			85	0				0	
81			86	0				0	
82			87	0				0	
83			88	0				0	
84			89	0				0	
85			81	1.00					

	A	B	C	D	E	F	G	H	I
1									
2									
3	Common Dose & Toxicity Factors		Grid	Pr.g	Cumulative Pr.g	Belg	Incremental Belg	ILCRres.be.g	ILCRres.be.g
4	SPe	4.3	1	0			0		
5	IngRad	1000	2	0			0		
6	Fa	1	3	0			0		
7	Fi	1	4	0			0		
8	BFa.be	1	5	0			0		
9	EFres	350	6	0			0		
10	EDres	350	7	0			0		
11	UCFm	0.000001	8	0			0		
12	BW	50	9	0			0		
13	BFW.be	1	11	0			0		
14	AT	70	12	0			0		
15	UCR2	365.25	13	0			0		
16	Common Dose & Toxicity Factor		=B4*B5*B6*B7*B8*B9*B10*B11/(B12*B13*B14*B15)	14	0		0		
17	Belb	4	15	0			0		
18			16	0			0		
19	ILCRres.be	=E16*B17*B18*B19	17	0			0		
20	RANDOM	=RAND()	18	0			0		
21			19	0			0		
22			21	0			0		
23			22	0			0		
24			23	0			0		
25			24	0			0		
26			25	0			0		
27			26	0			0		
28			27	0			0		
29			28	0			0		
30			29	0			0		
31			31	0.5	=D31+E30	0.500000 =F31-\$B\$17	=IF(\$B\$16*G31<0.0,\$B\$16*G31)	=H31*D31	
32			32	0			0		
33			33	0			0		
34			34	0			0		
35			35	0			0		
36			36	0			0		
37			37	0			0		
38			38	0			0		
39			39	0			0		
40			41	0.5	=D40+E39	0.500000 =F40-\$B\$17	=IF(\$B\$16*G40<0.0,\$B\$16*G40)	=H40*D40	
41			42	0			0		
42			43	0			0		
43			44	0			0		
44			45	0			0		
45			46	0			0		
46			47	0			0		
47			48	0			0		
48			49	0			0		
49			51	0			0		
50			52	0			0		
51			53	0			0		
52			54	0			0		
53			55	0			0		
54			56	0			0		
55			57	0			0		
56			58	0			0		
57			59	0			0		
58			61	0			0		
59			62	0			0		
60			63	0			0		
61			64	0			0		
62			65	0			0		
63			66	0			0		
64			67	0			0		
65			68	0			0		
66			69	0			0		
67			71	0			0		
68			72	0			0		
69			73	0			0		
70			74	0			0		
71			75	0			0		
72			76	0			0		
73			77	0			0		
74			78	0			0		
75			79	0			0		
76			81	0			0		
77			82	0			0		
78			83	0			0		
79			84	0			0		
80			85	0			0		
81			86	0			0		
82			87	0			0		
83			88	0			0		
84			89	0			0		
85			91	=SUM(D4:D84)					

Appendix O



MONTGOMERY WATSON

Appendix O

Kriging Results for Radium-226 Concentrations in Surface Soil

Grid-Specific Statistics for Radium-226 Surface Soil Concentrations On and Near the Monsanto Soda Springs Plant		
Grid	Mean	[Ra-226]g (pCi/g)* Standard Deviation
1	1.45	1.00
2	1.23	0.62
3	1.22	0.58
4	1.35	0.66
5	1.42	0.76
6	1.42	0.80
7	1.34	0.70
8	1.48	0.94
9	1.55	1.18
11	1.34	0.83
12	1.23	0.54
13	1.58	0.68
14	1.92	0.78
15	1.84	0.82
16	1.53	0.74
17	1.33	0.60
18	1.36	0.68
19	1.45	0.93
21	1.34	0.77
22	1.64	0.73
23	2.4	0.85
24	3.4	1.20
25	3.0	1.27
26	2.1	1.01
27	1.59	0.80
28	1.45	0.81
29	1.39	0.83
31	1.34	0.71
32	1.93	0.93
33	2.7	1.16
34	3.5	1.69
35	3.3	1.54
36	2.4	1.17
37	1.85	0.96
38	1.61	0.96
39	1.38	0.78
41	1.62	0.93
42	2.2	1.16
43	3.3	1.60
44	3.5	1.91
45	3.7	1.90
46	2.9	1.48
47	2.2	1.27
48	1.74	1.08
49	1.55	0.96
51	1.52	0.79
52	2.4	1.24
53	3.5	1.73
54	4.6	2.5
55	4.0	2.1
56	3.0	1.52
57	2.2	1.22
58	1.78	1.02
59	1.58	0.91
61	1.78	0.99
62	2.8	1.35
63	4.8	2.0
64	5.2	2.6
65	4.6	2.3
66	2.9	1.27
67	2.0	1.00
68	1.58	0.75
69	1.53	0.80
71	1.52	0.76
72	2.8	1.23
73	5.1	1.97
74	5.6	2.2
75	5.1	1.89
76	3.0	1.12
77	1.68	0.74
78	1.33	0.64
79	1.35	0.70
81	1.56	0.84
82	1.98	0.87
83	3.2	1.47
84	3.7	1.67
85	3.2	1.27
86	2.2	0.98
87	1.24	0.53
88	1.11	0.49
89	1.25	0.64
background	1.70	0.50

*Grid-specific concentrations of radium-226 in surface soil.

Appendix P



MONTGOMERY WATSON

Appendix P

Derivation of a Thin-Shell Geometry Factor for External Gamma Radiation Exposures

MEMORANDUM



MONTGOMERY WATSON

To: Bob Geddes, Monsanto
From: Bill Wright *WBW*
Subject: Corrections for the Off-Site External Radiation Risk Calculations
Date: December 9, 1994
Job No.: 1183.0040

Per your request, I have reviewed the analysis of the off-site residential scenario for the Monsanto Soda Springs Plant which was conducted by Leo Lowe, Ph.D., who is based in SENES's Toronto office. The analysis was forwarded to me by Dan Hrebenyk, and I have discussed the analysis with Dr. Lowe.

To focus discussion, I am taking the liberty of restating those points of Dr. Lowe's which I believe to be germane. I am proceeding in this manner in the interest of EPA-10's time concerns related to the publication of their baseline risk assessment report.

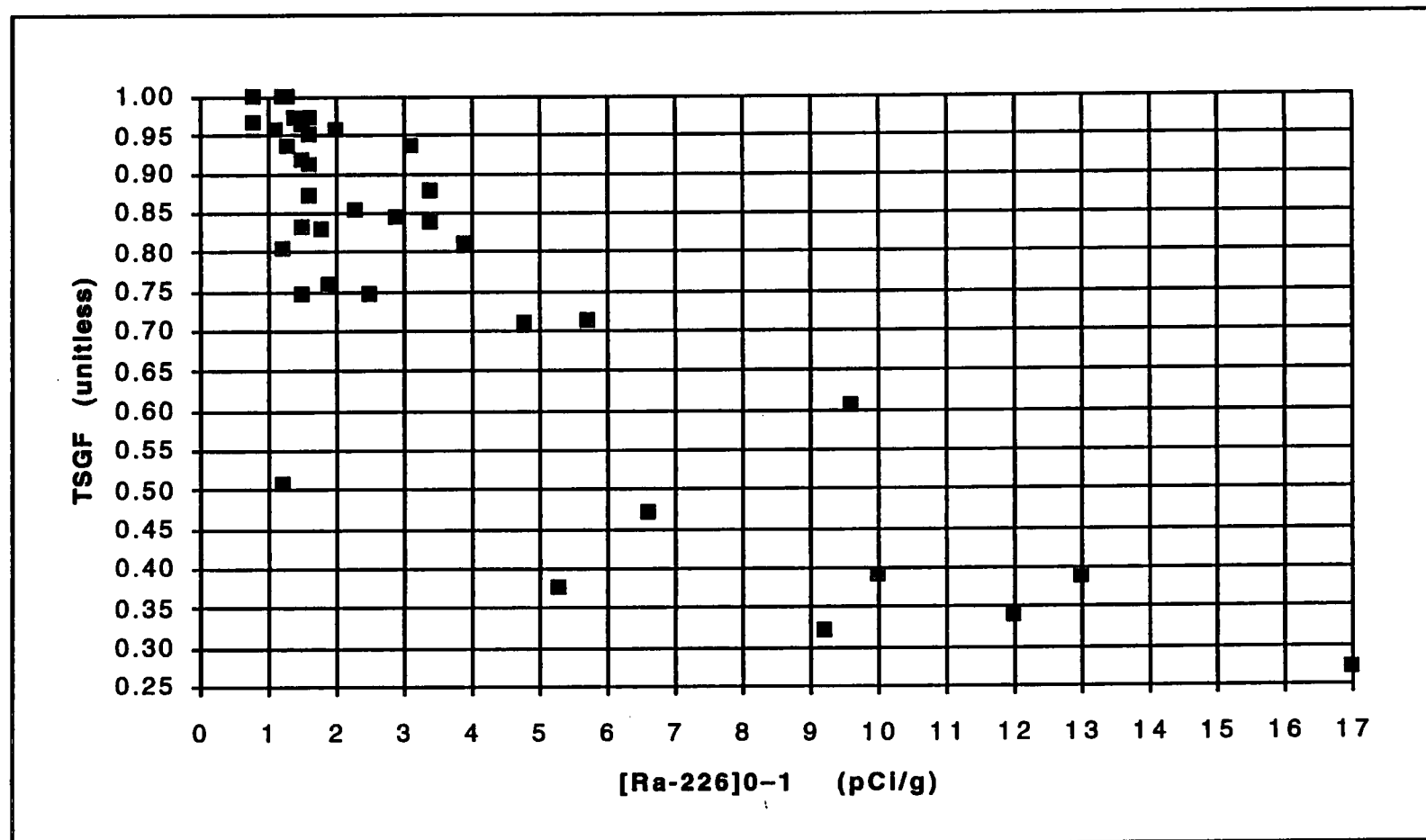
Dr. Lowe's main point is that the gamma dose above a source material is dependent on the thickness of that material. Dr. Lowe's analysis indicates that the external radiation model being used by EPA-10 and Monsanto to assess potential risks attributable to gamma radiation emanating from soil or stockpiles applies only if the soil or stockpiled material is infinitely thick. In practice, infinitely thick can be regarded as a material thickness greater than about 25 centimeters (10 inches) for a typical natural composition of gamma emitters. If the thickness of the material containing elevated levels of gamma emitters—in this case, ^{226}Ra —is less than this, the dose estimate must be decreased in a manner inversely proportional to the thickness of the material (*i.e.*, thin layers create less of a dose than thick layers).

Dr. Lowe has provided a figure, which is attached, from the following NCRP report:

National Council on Radiation Protection and Measurements, 1987, *Exposure of the Population in the United States and Canada from Natural Background Radiation*, NCRP Report No. 94, Bethesda, Maryland.

As ^{226}Ra is a naturally occurring gamma emitter, I believe it is reasonable to assume that the NCRP figure provided by Dr. Lowe can be used to approximate conditions at the Monsanto plant. I think we can agree that the material stockpiles at the site exceed a thickness of 10 inches; thus, EPA-10's risk estimates for on-site workers do not need to be adjusted for the thickness of the radiation source material. (This is not an endorsement of EPA-10's model; the Monsanto on-site risk model will be adjusted for those grids within the site where it is appropriate to do so).

For those portions of the Monsanto study area outside the plant fence line, data are available for the 0-to-1-inch stratum, the 0-to-6-inch stratum, and the 6-to-12-inch stratum. The attached NCRP figure indicates that the dose contribution from the 0-to-1-inch stratum (assuming that the ^{226}Ra is uniformly distributed within the stratum) is 27% of what would be assumed under an infinitely-thick-source hypothesis. The 1-to-6-inch stratum would contribute 54% (the difference between 81% and 27%) of what would be assumed under an infinitely-thick-source hypothesis. (The ^{226}Ra concentration in the 1-to-6-inch stratum is estimated to be the thickness-weighted difference between the 0-to-6-inch stratum and the 0-to-1-inch stratum, bearing in mind that it is

Figure P-1. Scatter Plot — Surface ^{226}Ra Concentration vs. Thin-Shell Geometry Factor.

Montgomery Watson

Table P-4. Regression Statistics for the Thin-Shell Geometry Factor.

<i>Regression Statistics</i>						
R	-0.85					
R-Squared	0.72					
Standard Error	0.118					
Observations	41					
<i>Analysis of Variance</i>	<i>df</i>	<i>Sum of Squares</i>	<i>Mean Square</i>	<i>F</i>	<i>p</i>	
Total	40	1.97				
Regression	1	1.43	1.43	101.53	2.1E-12	
Residual	39	0.55	0.0140			
Lack of Fit	25	0.35	0.0138	0.96	0.55	
Pure Error	14	0.20	0.0144			
	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Statistic</i>	<i>p</i>	<i>Lower 95%</i>	<i>Upper 95%</i>
b	0.97	0.026	37.37	1.00E-32	0.91	1.02
m	-0.050	0.0049	-10.08	1.55E-12	-0.059	-0.040

Table P-1. Thin-Shell Geometry Factors (TSGFs) for Soils in the Vicinity of the Monsanto Soda Springs Plant.

Sampling Station	[Ra-226]0-1 (pCi/g)	[Ra-226]0-6 (pCi/g)†	[Ra-226]1-6 (pCi/g)†	Effective [Ra-226] (pCi/g)	TSGF (unitless)††
MS2-34	0.79	0.63	0.60	0.76	0.97
MS2-27	0.80	1.6	1.8	1.39	1.00
MS2-26	1.1	1.0	0.98	1.05	0.96
MS2-1	1.2	0.29	0.11	0.61	0.51
MS2-2	1.2	1.2	1.2	1.20	1.00
MS2-17	1.2	1.2	1.2	1.20	1.00
MS2-35	1.2	0.84	0.77	0.97	0.81
MS2-13	1.3	1.2	1.2	1.22	0.94
MS2-24	1.3	1.5	1.5	1.41	1.00
MS2-28	1.3	1.4	1.4	1.35	1.00
MS2-16	1.4	1.4	1.4	1.36	0.97
S2-05	1.5	1.4	1.4	1.38	0.92
MS2-8	1.5	1.0	0.90	1.12	0.75
MS2-14	1.5	1.2	1.1	1.25	0.83
MS2-22	1.5	1.4	1.4	1.38	0.92
MS2-29	1.5	1.5	1.5	1.44	0.96
S-07	1.6	1.5	1.5	1.46	0.91
MS2-6	1.6	1.6	1.6	1.52	0.95
MS2-12	1.6	1.4	1.4	1.39	0.87
MS2-25	1.6	1.7	1.7	1.56	0.97
MS2-10	1.8	1.5	1.4	1.49	0.83
MS2-9	1.9	1.4	1.3	1.44	0.76
MS2-5	2.0	2.1	2.1	1.91	0.96
S-16	2.3	2.1	2.1	1.96	0.85
MS2-11	2.5	1.9	1.8	1.86	0.75
MS2-4	2.9	2.7	2.7	2.4	0.84
MS2-30	3.1	3.4	3.4	2.9	0.94
S-01	3.4	3.4	3.4	3.0	0.88
S2-09	3.4	3.2	3.2	2.9	0.84
MS2-3	3.4	3.4	3.4	3.0	0.88
S-08	3.9	3.6	3.5	3.2	0.81
S-15	4.8	3.7	3.5	3.4	0.71
S2-06	5.3	1.4	0.62	1.99	0.38
MS2-7	6.6	2.8	2.0	3.1	0.47
S-12	5.7	4.5	4.3	4.1	0.71
S-04	9.2	1.9	0.44	2.9	0.32
S-13	9.6	6.2	5.5	5.8	0.60
S-10	10	3.2	1.8	3.9	0.39
S2-03	12	2.9	1.1	4.1	0.34
S-14	13	4.2	2.4	5.1	0.39
S2-11	17	1.8	-1.2	4.1	0.27
Averages	3.7	2.1	1.8		

†Shaded values represent the average of analytical results from duplicate samples.

††Shaded values are default values set at the physical limits of the TSGF; calculated values were outside these limits (i.e., either > 1.00 or < 0.27).

Table P-1. ^{226}Ra Concentrations in the 6-to-12-in Stratum of Background Soils.

Background Station	[Ra-226]6-12† (pCi/g)
BACKGROUND3	1.0
BACKGROUND1	1.2
BACKGROUND2	1.2
KM BACKGROUND5	1.0
KM BACKGROUND6	1.7
KM BACKGROUND7	1.3
Average	1.2

†Shaded values represent the average of analytical results from duplicate samples.

Table P-2. Thin-Shell Geometry Factors (TSGFs) for Background Soils.

Background Station	[Ra-226]0-1 (pCi/g)	[Ra-226]0-6 (pCi/g)	[Ra-226]1-6 (pCi/g)	Effective [Ra-226] (pCi/g)	TSGF (unitless)
BACKGROUND1	1.3	1.3	1.3	1.3	0.99
BACKGROUND2	1.1	1.2	1.2	1.2	1.08
BACKGROUND3	0.80	1.0	1.0	1.0	1.26
Averages	1.1	1.2	1.2		

Attachment P-1 — Development of a Thin-Shell Geometry Distribution

The preceding memorandum indicates that a thin-shell geometry factor, which ranges from 0.27 to 1.00, can be defined as:

$$\text{TSGF} = \left(0.27 \times [^{226}\text{Ra}]_{0-1}\right) + \left(0.54 \times [^{226}\text{Ra}]_{1-6}\right) + \left(0.19 \times [^{226}\text{Ra}]_{6-12}\right)$$

where:

- TSGF is the thin-shell geometry factor (unitless);
- $[^{226}\text{Ra}]_{0-1}$ is the concentration of ^{226}Ra in the 0-to-1-in soil stratum (pCi/g);
- $[^{226}\text{Ra}]_{1-6}$ is the concentration of ^{226}Ra in the 1-to-6-in soil stratum (pCi/g); and,
- $[^{226}\text{Ra}]_{6-12}$ is the concentration of ^{226}Ra in the 6-to-12-in soil stratum (pCi/g).

Assuming that soils in the 6-to-12-in stratum are not affected, $[^{226}\text{Ra}]_{6-12}$ can be represented by 1.2 pCi/g, the average of six background samples from that stratum (see Table P-1). Table P-2 shows the TSGF values for the three background locations for which paired data are available for the 0-to-1-in and 1-to-6-in strata. Not surprisingly, the TSGF can exceed the upper limit of 1.00 under background conditions due to noise (minor fluctuations in concentration at different depths). Thus, in determining a TSGF for any given point, any exceedance of the physical limits of the distribution will be substituted with the appropriate limit as a default.

Appendix J of the Phase II RI Report provides paired data for 41 soil sampling stations. The resulting TSGFs for each of these locations are listed in Table P-3. TSGF is significantly and negatively correlated with $[^{226}\text{Ra}]_{0-1}$ ($r = -0.85$; see the regression statistics in Table P-4 and the scatter plot in Figure P-1). The regression analysis summarized in Table P-4 shows that TSGF can be represented by the following equation:

$$\text{TSGF} = \left(N(-0.050, 0.0049) \times [^{226}\text{Ra}]_{0-1}\right) + N(0.97, 0.026)$$

where:

- $N(-0.050, 0.0049)$ is the slope of the regression equation (a normal distribution with a mean of -0.050 g/pCi and a standard deviation of 0.0049 g/pCi); and,
- $N(0.97, 0.026)$ is the intercept of the regression equation (unitless).

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INTL SKYLINE GOLD

TEL: 604 683 7449

P. 005

DEC-06-1994 12:08

SERIES CONSULTANTS

U.S. NCAAP REPORT #94
(1987)

GO / 4. RADIONUCLIDES IN THE EARTH

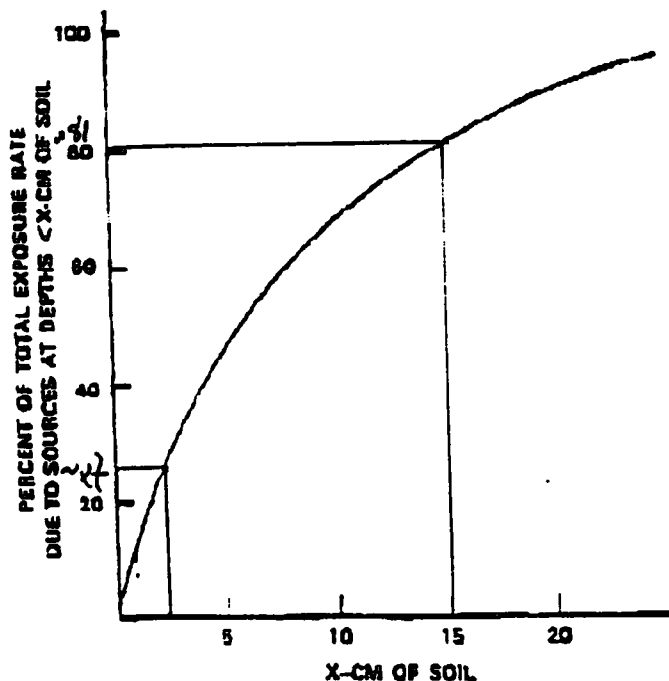


Fig. 4.1. Percent of total exposure rate due to gamma-emitting sources at various depths in the soil for a typical natural emitter source composition.

radioactivity of the sedimentary bedrock is not abnormal. Similar instances involving smaller areas and populations probably occur in other parts of the United States.

Biochemical processes modify the inherent radioactivity of the soil in several ways. The development of root systems stabilizes the soil as its water content increases. Humic acids accelerate decomposition of the rock material, resulting in smaller grain sizes, and greater water content, greater porosity, and less permeability for the soil. The decomposition of organic matter tends to change the lower soil from an oxidizing to a reducing environment, reducing uranium from its mobile hexavalent state to its immobile tetravalent state, and decomposing the hydrous iron oxides that entrap radium and other elements present in minute concentration. The acid conditions in some soils should also minimize retention of radionuclides taken up by calcium carbonate. The overall effect of soil development is to reduce the average level of external radiation (Table 4.3) and to reduce the range of concentration of the radionuclides in comparison with the source rocks.

December 9, 1994

EPA-10 is proposing use of a DRF of 0.80.

With the two modifications addressed above, the geometric dose correction and the dose-reduction factor correction, the EPA-10 draft risk estimates for the on-site residential scenario should decrease about 10-fold.

cc: T. Brincefield, EPA-HQ
S. Whittaker, E&E-Seattle
D. Banton, Golder Associates-Redmond
D. Hrebenyk, SENES-Vancouver
L. Lowe, SENES-Toronto

Corrected for typographic errors on 12 February 1996. It should be noted that the final modeling has been modified relative to what is mentioned in this memorandum. Specifically, the on-site occupational models have not incorporated a thin-shell geometry factor (TSGF). The TSGF is only used for the future off-site residential models. The factor is omitted from the on-site occupational model because the material stockpiles, which are for all practical purposes infinitely thick, contribute far more to worker exposures than do on-site soils.

the increment above background that is of interest.) The below-6-inch stratum would contribute 19% (the difference between 100% and 81%) of what would be assumed under an infinitely-thick-source hypothesis.

Assume that the following generalized conditions, which are roughly representative of fenceline conditions at the site:

- ^{226}Ra concentration in the 0-to-1-inch soil stratum—7X;
- ^{226}Ra concentration in the 0-to-6-inch soil stratum—4X;
- ^{226}Ra concentration in the 6-to-12-inch soil stratum—1X; and,
- ^{226}Ra concentration in background soil—1X (assuming a uniform background concentration from the surface through 12 inches).

The ^{226}Ra concentration in the 1-to-6-inch stratum is thus 3X, and the incremental concentrations of interest are:

- 0-to-1-inch stratum—6X (*i.e.*, 7X-1X);
- 1-to-6-inch stratum—2.4X [*i.e.*, [(6 inches×4X-1 inch×7X)+(6 inches-1 inch)]-1X]; and,
- 6-to-12-inch stratum—0X (*i.e.*, 1X-1X).

Thus, the effective incremental concentration in the soil is:

$$(6X \times 0.27) + (2.4X \times 0.54) + (0X \times 0.19) = 1.6X + 1.3X + 0X = 2.9X.$$

In summary, the effective incremental concentration is a bit less than half that derived from use of the surface data and an infinitely-thick-source hypothesis. This reduction is solely a function of the geometry of the source material.

A second point brought out in Dr. Lowe's analysis is related to the dose-reduction factor (*i.e.*, one minus the shielding factor used by EPA-10) for the off-site residential scenario. In his analysis, Dr. Lowe assumes that a resident spends 75% of his time indoors, and that the house shields 67% of the radiation from the soil:

$$\text{DRF} = (0.25 \times 1) + (0.75 \times 0.33) = 0.50.$$

This assumes that one is unshielded when outdoors. It also assumes that the house is built on top of the source material. Because the elevated ^{226}Ra is deposited within the upper 6 inches of the soil column, I believe it is unreasonable to assume the existence of any source material beneath the house. If the house were constructed prior to construction of the Monsanto plant, there would be no way for the ^{226}Ra to become elevated beneath the house; if the house were to be constructed now or later, any sort of foundation work should serve to eliminate the thin shell of elevated ^{226}Ra .

Therefore, I believe it is reasonable to assume that the DRF should be reduced to 0.25 (given the indoor-time assumption of 75% and a deterministic modeling framework):

$$\text{DRF} = (0.25 \times 1) + (0.75 \times 0) = 0.25.$$

Appendix Q



MONTGOMERY WATSON

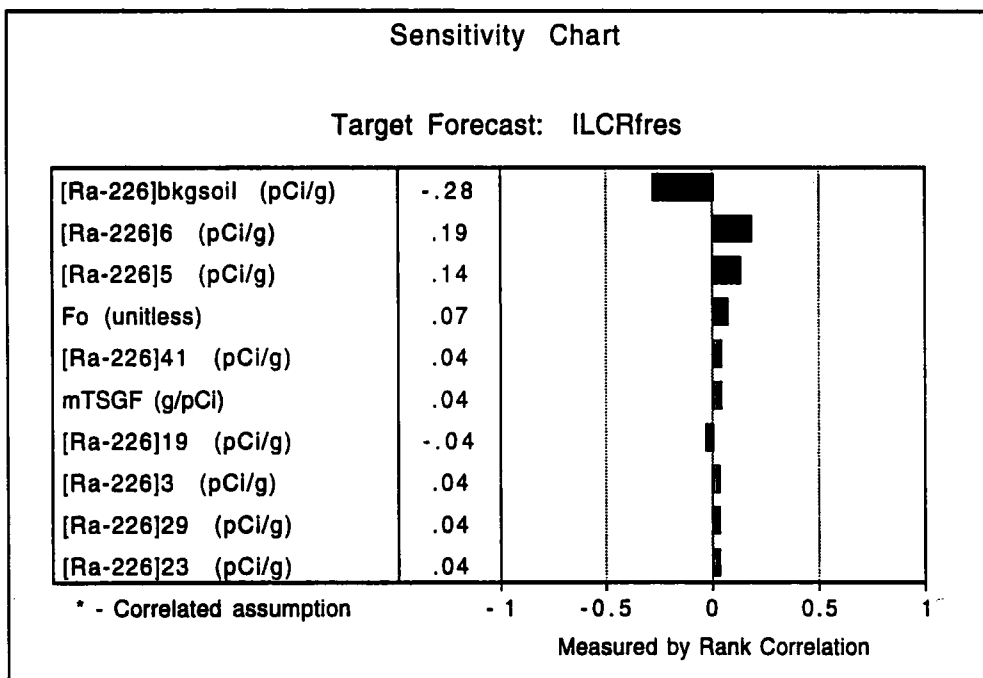
Appendix Q

Crystal Ball® Report—Future Residential Cancer Risk Model

Crystal Ball Report:
Future Residential Subscenario for Monsanto's Soda Springs Plant

Simulation started on Fri, Feb 23, 1996 at 10:10:28

Simulation stopped on Fri, Feb 23, 1996 at 10:52:09



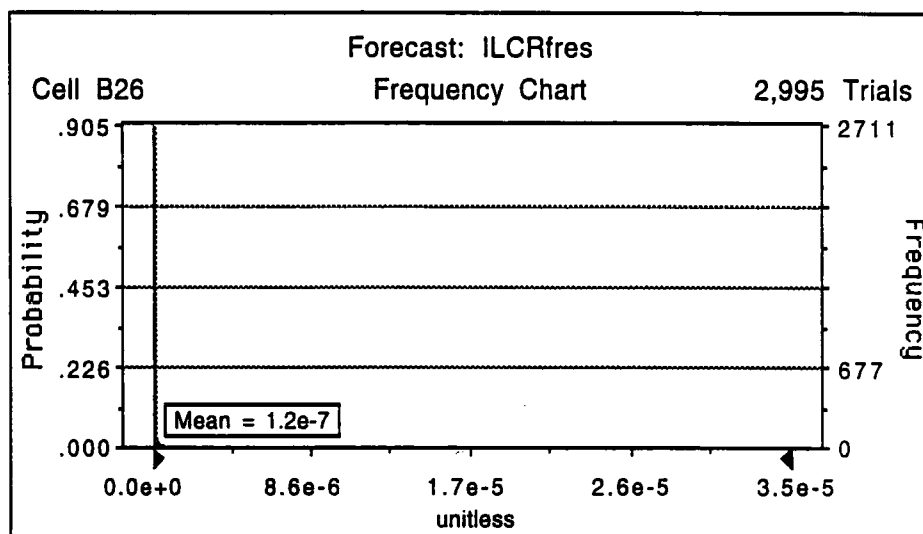
Sum of r-squared values = 0.168

Only the ten "most sensitive" variables are shown above

Forecast: ILCRfres

Cell: B26

Statistics:	Value
Trials	2,995
Mean	1.18E-07
Median	0
Standard deviation	1.00E-06
Variance	1.01E-12
Coefficient of variation	8.5



Forecast: ILCRfres (cont'd)

Cell: B26

Percentiles:

<u>Percentile</u>	<u>ILCRfres</u>
0.03%	0
5.00%	0
10.00%	0
15.00%	0
20.00%	0
25.00%	0
30.00%	0
35.00%	0
40.00%	0
45.00%	0
50.00%	0
55.00%	0
60.00%	0
65.00%	0
70.00% (Point estimate for southern II area)	0
75.00%	6.2E-10
80.00%	9.0E-09
85.00%	3.2E-08
90.00%	1.02E-07
95.00%	3.3E-07
98.00%	1.10E-06
99.00%	2.2E-06
99.90%	1.65E-05
99.97%	3.5E-05
> 99.97% (Point estimate for northern II area)	1E-04
> 99.97% (Point estimate for northern I and southern I areas)	2E-03

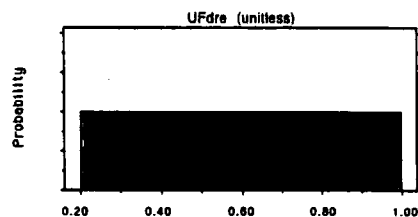
End of Forecast

Assumptions**Assumption: UFdre (unitless)****Cell: B4**

Uniform distribution with parameters:

Minimum	0.20
Maximum	1.00

Mean value in simulation was 0.59

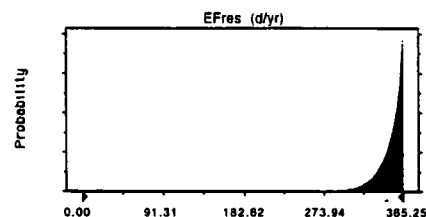
**Assumption: EFres (d/yr)****Cell: B6**

Beta distribution with parameters:

Alpha	21
Beta	0.92
Scale	365.25

Selected range is from 0 to 365.25

Mean value in simulation was 350



Correlated with:

FI (unitless) (B9)	0.50
--------------------	------

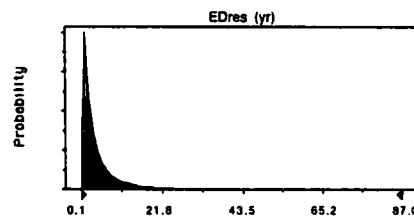
Assumption: EDres (yr)**Cell: B7**

Lognormal distribution with parameters:

Mean	4.6
Std. deviation	8.7

Selected range is from 0 to ∞

Mean value in simulation was 4.5



Assumption: Fo (unitless)

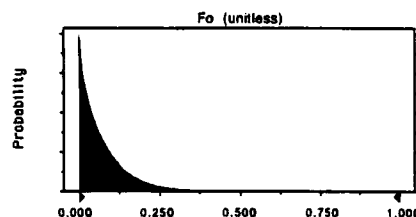
Cell: B8

Beta distribution with parameters:

Alpha	0.92
Beta	11.6
Scale	1.00

Selected range is from 0 to 1.00

Mean value in simulation was 0.073

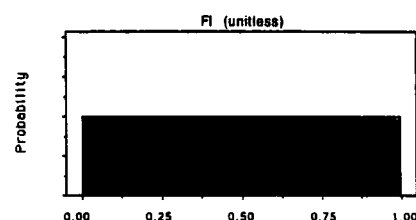
**Assumption: FI (unitless)**

Cell: B9

Uniform distribution with parameters:

Minimum	0
Maximum	1.00

Mean value in simulation was 0.50



Correlated with:

EFres (d/yr) (B6)

0.50

Assumption: mTSGF (g/pCi)

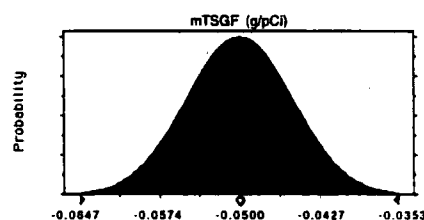
Cell: B12

Normal distribution with parameters:

Mean	-0.050
Std. deviation	0.0049

Selected range is from $-\infty$ to ∞

Mean value in simulation was -0.050

**Assumption: bTSGF (unitless)**

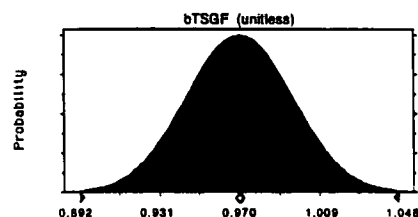
Cell: B13

Normal distribution with parameters:

Mean	0.97
Std. deviation	0.026

Selected range is from $-\infty$ to ∞

Mean value in simulation was 0.97



Assumption: [Ra-226]bkgsoil (pCi/g)

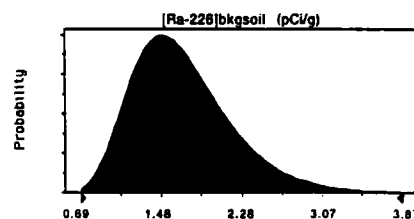
Cell: B14

Lognormal distribution with parameters:

Mean	1.70
Std. deviation	0.50

Selected range is from 0 to ∞

Mean value in simulation was 1.71

**Assumption: [Ra-226]1 (pCi/g)**

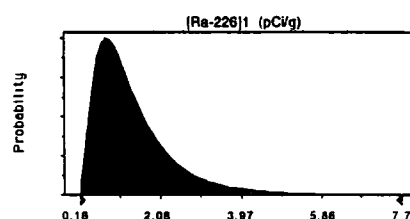
Cell: F4

Lognormal distribution with parameters:

Mean	1.45
Std. deviation	1.00

Selected range is from 0 to ∞

Mean value in simulation was 1.44

**Assumption: [Ra-226]3 (pCi/g)**

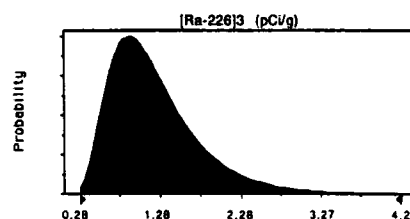
Cell: F6

Lognormal distribution with parameters:

Mean	1.22
Std. deviation	0.58

Selected range is from 0 to ∞

Mean value in simulation was 1.22

**Assumption: [Ra-226]4 (pCi/g)**

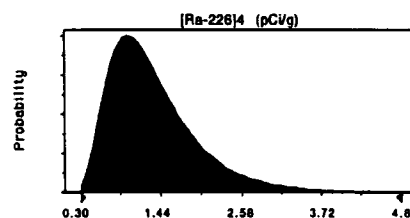
Cell: F7

Lognormal distribution with parameters:

Mean	1.35
Std. deviation	0.66

Selected range is from 0 to ∞

Mean value in simulation was 1.36



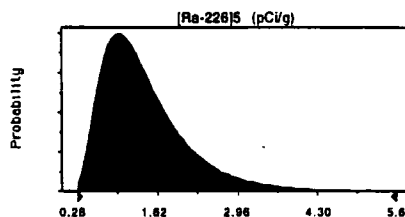
Assumption: [Ra-226]5 (pCi/g)**Cell: F8**

Lognormal distribution with parameters:

Mean	1.42
Std. deviation	0.76

Selected range is from 0 to ∞

Mean value in simulation was 1.44

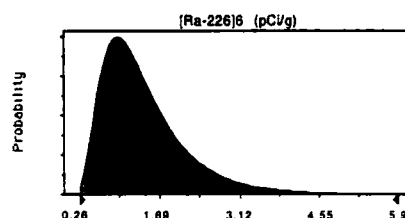
**Assumption: [Ra-226]6 (pCi/g)****Cell: F9**

Lognormal distribution with parameters:

Mean	1.42
Std. deviation	0.80

Selected range is from 0 to ∞

Mean value in simulation was 1.43

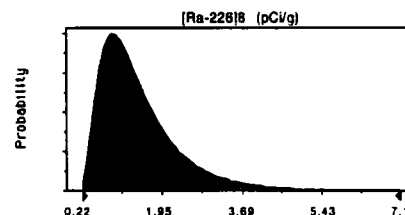
**Assumption: [Ra-226]8 (pCi/g)****Cell: F11**

Lognormal distribution with parameters:

Mean	1.48
Std. deviation	0.94

Selected range is from 0 to ∞

Mean value in simulation was 1.48

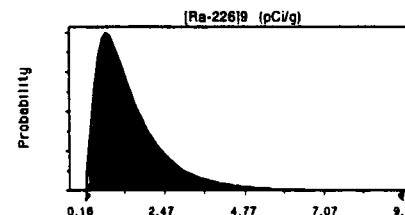
**Assumption: [Ra-226]9 (pCi/g)****Cell: F12**

Lognormal distribution with parameters:

Mean	1.55
Std. deviation	1.18

Selected range is from 0 to ∞

Mean value in simulation was 1.55



Assumption: [Ra-226]11 (pCi/g)

Cell: F13

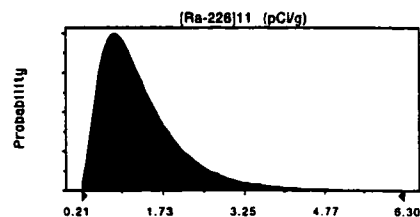
Lognormal distribution with parameters:

Mean 1.34

Std. deviation 0.83

Selected range is from 0 to ∞

Mean value in simulation was 1.35

**Assumption: [Ra-226]13 (pCi/g)**

Cell: F15

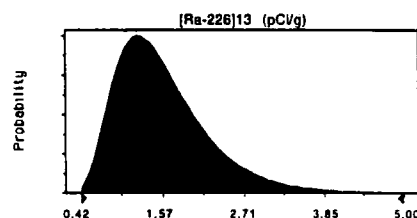
Lognormal distribution with parameters:

Mean 1.58

Std. deviation 0.68

Selected range is from 0 to ∞

Mean value in simulation was 1.57

**Assumption: [Ra-226]14 (pCi/g)**

Cell: F16

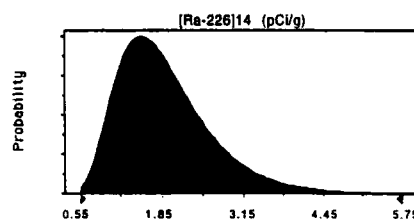
Lognormal distribution with parameters:

Mean 1.92

Std. deviation 0.78

Selected range is from 0 to ∞

Mean value in simulation was 1.91

**Assumption: [Ra-226]16 (pCi/g)**

Cell: F18

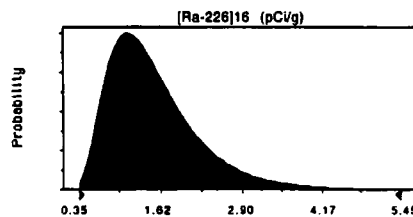
Lognormal distribution with parameters:

Mean 1.53

Std. deviation 0.74

Selected range is from 0 to ∞

Mean value in simulation was 1.55



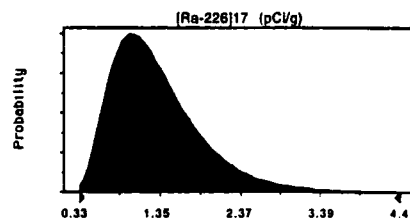
Assumption: [Ra-226]17 (pCi/g)**Cell: F19**

Lognormal distribution with parameters:

Mean	1.33
Std. deviation	0.60

Selected range is from 0 to ∞

Mean value in simulation was 1.32

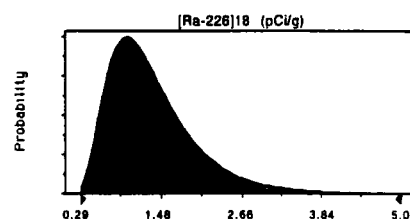
**Assumption: [Ra-226]18 (pCi/g)****Cell: F20**

Lognormal distribution with parameters:

Mean	1.36
Std. deviation	0.68

Selected range is from 0 to ∞

Mean value in simulation was 1.37

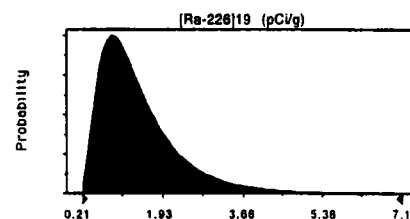
**Assumption: [Ra-226]19 (pCi/g)****Cell: F21**

Lognormal distribution with parameters:

Mean	1.45
Std. deviation	0.93

Selected range is from 0 to ∞

Mean value in simulation was 1.46

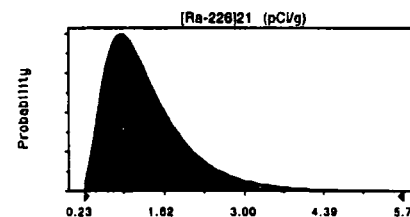
**Assumption: [Ra-226]21 (pCi/g)****Cell: F22**

Lognormal distribution with parameters:

Mean	1.34
Std. deviation	0.77

Selected range is from 0 to ∞

Mean value in simulation was 1.35



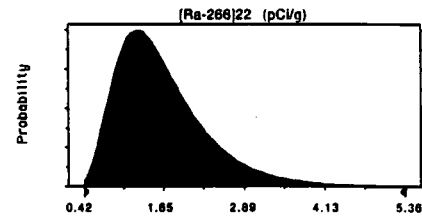
Assumption: [Ra-226]22 (pCi/g)**Cell: F23**

Lognormal distribution with parameters:

Mean	1.64
Std. deviation	0.73

Selected range is from 0 to ∞

Mean value in simulation was 1.63

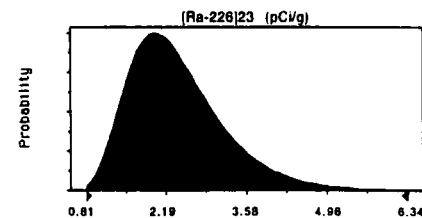
**Assumption: [Ra-226]23 (pCi/g)****Cell: F24**

Lognormal distribution with parameters:

Mean	2.4
Std. deviation	0.85

Selected range is from 0 to ∞

Mean value in simulation was 2.4

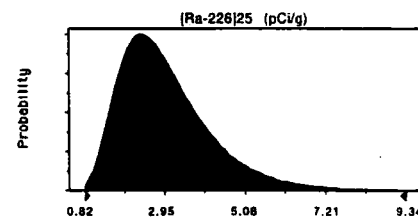
**Assumption: [Ra-226]25 (pCi/g)****Cell: F26**

Lognormal distribution with parameters:

Mean	3.0
Std. deviation	1.27

Selected range is from 0 to ∞

Mean value in simulation was 3.0

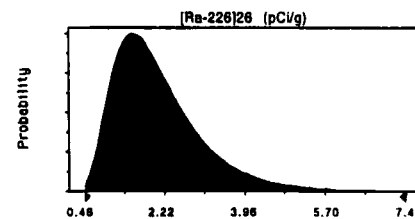
**Assumption: [Ra-226]26 (pCi/g)****Cell: F27**

Lognormal distribution with parameters:

Mean	2.1
Std. deviation	1.01

Selected range is from 0 to ∞

Mean value in simulation was 2.1



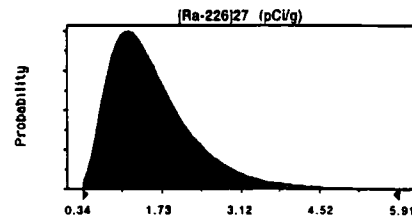
Assumption: [Ra-226]27 (pCi/g)**Cell: F28**

Lognormal distribution with parameters:

Mean	1.59
Std. deviation	0.80

Selected range is from 0 to ∞

Mean value in simulation was 1.58

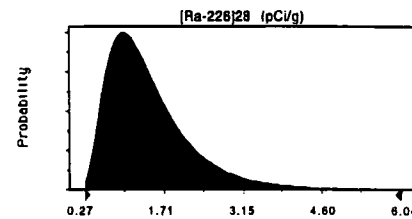
**Assumption: [Ra-226]28 (pCi/g)****Cell: F29**

Lognormal distribution with parameters:

Mean	1.45
Std. deviation	0.81

Selected range is from 0 to ∞

Mean value in simulation was 1.44

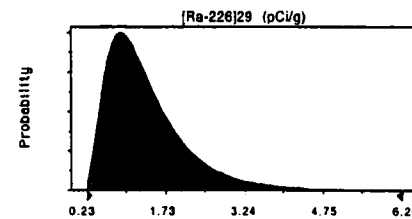
**Assumption: [Ra-226]29 (pCi/g)****Cell: F30**

Lognormal distribution with parameters:

Mean	1.39
Std. deviation	0.83

Selected range is from 0 to ∞

Mean value in simulation was 1.42

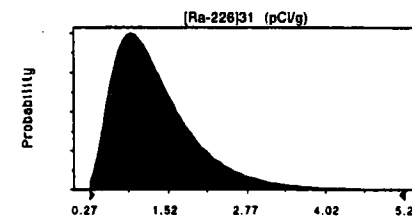
**Assumption: [Ra-226]31 (pCi/g)****Cell: F31**

Lognormal distribution with parameters:

Mean	1.34
Std. deviation	0.71

Selected range is from 0 to ∞

Mean value in simulation was 1.33



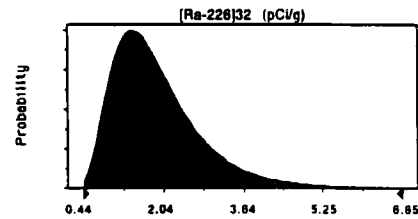
Assumption: [Ra-226]32 (pCi/g)**Cell: F32**

Lognormal distribution with parameters:

Mean	1.93
Std. deviation	0.93

Selected range is from 0 to ∞

Mean value in simulation was 1.91

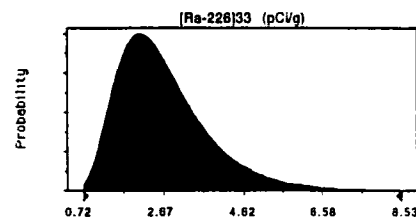
**Assumption: [Ra-226]33 (pCi/g)****Cell: F33**

Lognormal distribution with parameters:

Mean	2.7
Std. deviation	1.16

Selected range is from 0 to ∞

Mean value in simulation was 2.7

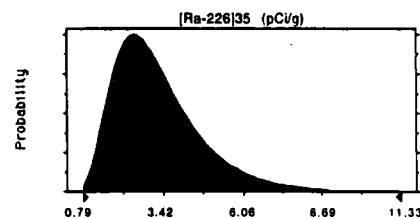
**Assumption: [Ra-226]35 (pCi/g)****Cell: F35**

Lognormal distribution with parameters:

Mean	3.3
Std. deviation	1.54

Selected range is from 0 to ∞

Mean value in simulation was 3.3

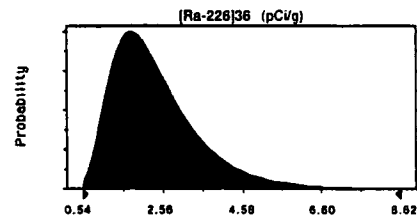
**Assumption: [Ra-226]36 (pCi/g)****Cell: F36**

Lognormal distribution with parameters:

Mean	2.4
Std. deviation	1.17

Selected range is from 0 to ∞

Mean value in simulation was 2.4



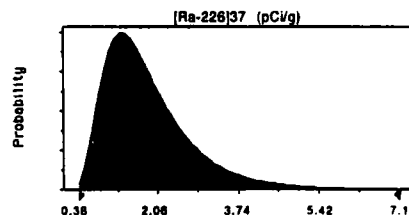
Assumption: [Ra-226]37 (pCi/g)**Cell: F37**

Lognormal distribution with parameters:

Mean	1.85
Std. deviation	0.96

Selected range is from 0 to ∞

Mean value in simulation was 1.86

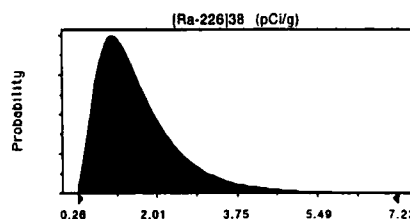
**Assumption: [Ra-226]38 (pCi/g)****Cell: F38**

Lognormal distribution with parameters:

Mean	1.61
Std. deviation	0.96

Selected range is from 0 to ∞

Mean value in simulation was 1.61

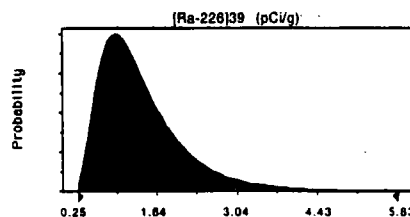
**Assumption: [Ra-226]39 (pCi/g)****Cell: F39**

Lognormal distribution with parameters:

Mean	1.38
Std. deviation	0.78

Selected range is from 0 to ∞

Mean value in simulation was 1.42

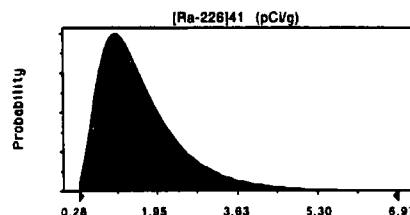
**Assumption: [Ra-226]41 (pCi/g)****Cell: F40**

Lognormal distribution with parameters:

Mean	1.62
Std. deviation	0.93

Selected range is from 0 to ∞

Mean value in simulation was 1.63



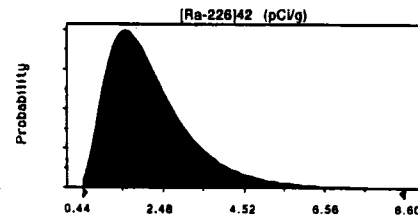
Assumption: [Ra-226]42 (pCi/g)

Cell: F41

Lognormal distribution with parameters:

Mean	2.2
Std. deviation	1.16

Selected range is from 0 to ∞
Mean value in simulation was 2.2

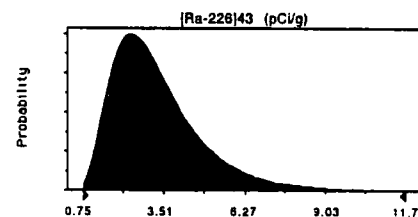
**Assumption: [Ra-226]43 (pCi/g)**

Cell: F42

Lognormal distribution with parameters:

Mean	3.3
Std. deviation	1.60

Selected range is from 0 to ∞
Mean value in simulation was 3.3

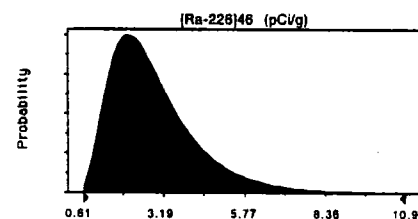
**Assumption: [Ra-226]46 (pCi/g)**

Cell: F45

Lognormal distribution with parameters:

Mean	2.9
Std. deviation	1.48

Selected range is from 0 to ∞
Mean value in simulation was 2.9

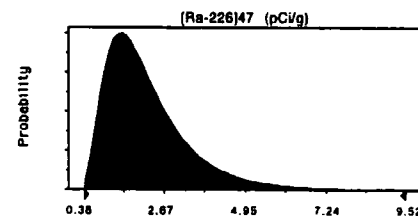
**Assumption: [Ra-226]47 (pCi/g)**

Cell: F46

Lognormal distribution with parameters:

Mean	2.2
Std. deviation	1.27

Selected range is from 0 to ∞
Mean value in simulation was 2.2



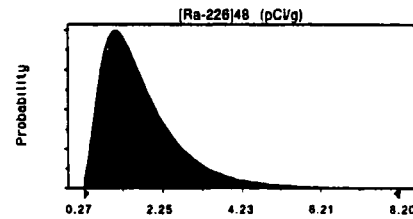
Assumption: [Ra-226]48 (pCi/g)**Cell: F47**

Lognormal distribution with parameters:

Mean	1.74
Std. deviation	1.08

Selected range is from 0 to ∞

Mean value in simulation was 1.73

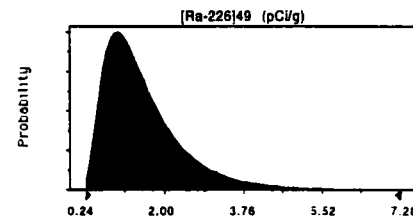
**Assumption: [Ra-226]49 (pCi/g)****Cell: F48**

Lognormal distribution with parameters:

Mean	1.55
Std. deviation	0.96

Selected range is from 0 to ∞

Mean value in simulation was 1.54

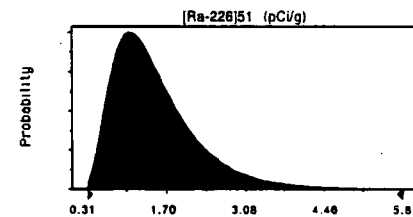
**Assumption: [Ra-226]51 (pCi/g)****Cell: F49**

Lognormal distribution with parameters:

Mean	1.52
Std. deviation	0.79

Selected range is from 0 to ∞

Mean value in simulation was 1.53

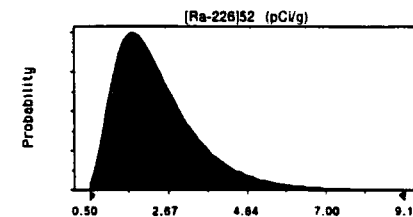
**Assumption: [Ra-226]52 (pCi/g)****Cell: F50**

Lognormal distribution with parameters:

Mean	2.4
Std. deviation	1.24

Selected range is from 0 to ∞

Mean value in simulation was 2.4



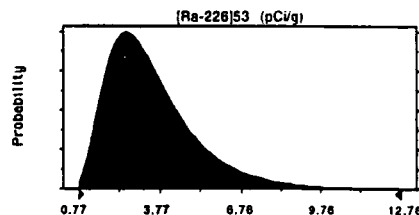
Assumption: [Ra-226]53 (pCi/g)

Cell: F51

Lognormal distribution with parameters:

Mean	3.5
Std. deviation	1.73

Selected range is from 0 to ∞
Mean value in simulation was 3.4

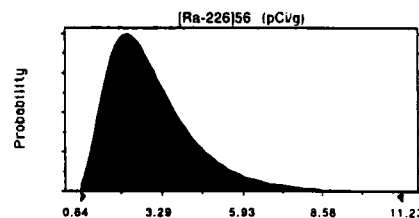
**Assumption: [Ra-226]56 (pCi/g)**

Cell: F54

Lognormal distribution with parameters:

Mean	3.0
Std. deviation	1.52

Selected range is from 0 to ∞
Mean value in simulation was 3.0

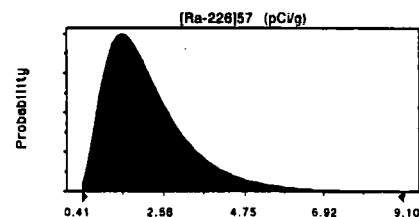
**Assumption: [Ra-226]57 (pCi/g)**

Cell: F55

Lognormal distribution with parameters:

Mean	2.2
Std. deviation	1.22

Selected range is from 0 to ∞
Mean value in simulation was 2.2

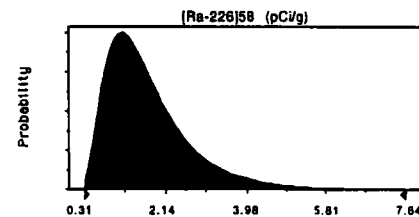
**Assumption: [Ra-226]58 (pCi/g)**

Cell: F56

Lognormal distribution with parameters:

Mean	1.78
Std. deviation	1.02

Selected range is from 0 to ∞
Mean value in simulation was 1.77



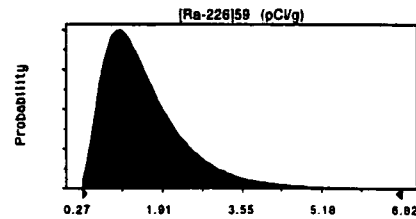
Assumption: [Ra-226]59 (pCi/g)**Cell: F57**

Lognormal distribution with parameters:

Mean	1.58
Std. deviation	0.91

Selected range is from 0 to ∞

Mean value in simulation was 1.59

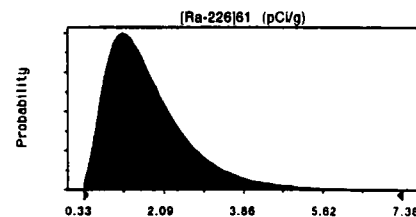
**Assumption: [Ra-226]61 (pCi/g)****Cell: F58**

Lognormal distribution with parameters:

Mean	1.78
Std. deviation	0.99

Selected range is from 0 to ∞

Mean value in simulation was 1.78

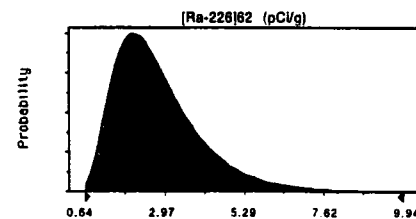
**Assumption: [Ra-226]62 (pCi/g)****Cell: F59**

Lognormal distribution with parameters:

Mean	2.8
Std. deviation	1.35

Selected range is from 0 to ∞

Mean value in simulation was 2.8

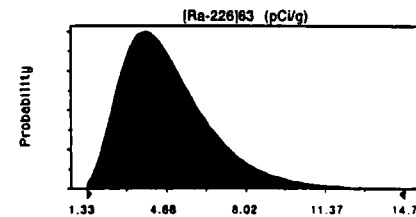
**Assumption: [Ra-226]63 (pCi/g)****Cell: F60**

Lognormal distribution with parameters:

Mean	4.8
Std. deviation	2.0

Selected range is from 0 to ∞

Mean value in simulation was 4.8



Assumption: [Ra-226]66 (pCi/g)**Cell: F63**

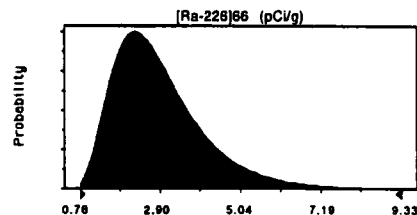
Lognormal distribution with parameters:

Mean 2.9

Std. deviation 1.27

Selected range is from 0 to ∞

Mean value in simulation was 2.9

**Assumption: [Ra-226]67 (pCi/g)****Cell: F64**

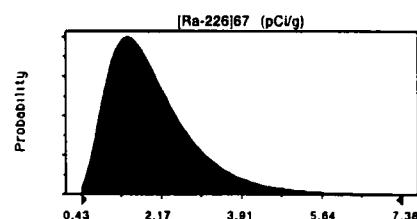
Lognormal distribution with parameters:

Mean 2.0

Std. deviation 1.00

Selected range is from 0 to ∞

Mean value in simulation was 2.0

**Assumption: [Ra-226]68 (pCi/g)****Cell: F65**

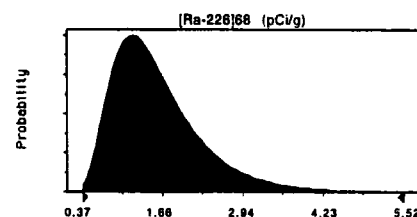
Lognormal distribution with parameters:

Mean 1.58

Std. deviation 0.75

Selected range is from 0 to ∞

Mean value in simulation was 1.57

**Assumption: [Ra-226]69 (pCi/g)****Cell: F66**

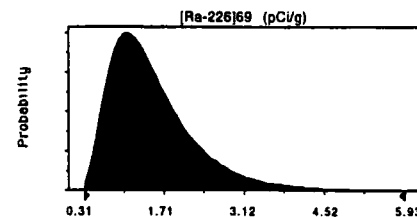
Lognormal distribution with parameters:

Mean 1.53

Std. deviation 0.80

Selected range is from 0 to ∞

Mean value in simulation was 1.53



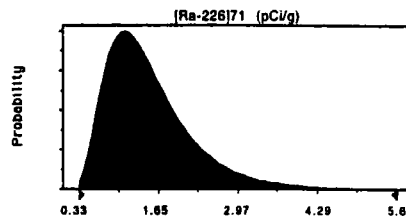
Assumption: [Ra-226]71 (pCi/g)**Cell: F67**

Lognormal distribution with parameters:

Mean	1.52
Std. deviation	0.76

Selected range is from 0 to ∞

Mean value in simulation was 1.52

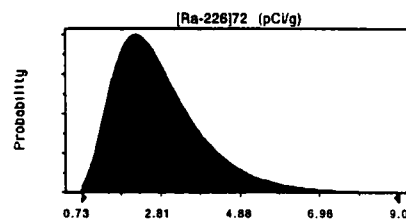
**Assumption: [Ra-226]72 (pCi/g)****Cell: F68**

Lognormal distribution with parameters:

Mean	2.8
Std. deviation	1.23

Selected range is from 0 to ∞

Mean value in simulation was 2.8

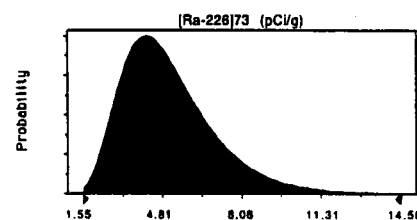
**Assumption: [Ra-226]73 (pCi/g)****Cell: F69**

Lognormal distribution with parameters:

Mean	5.1
Std. deviation	1.97

Selected range is from 0 to ∞

Mean value in simulation was 5.1

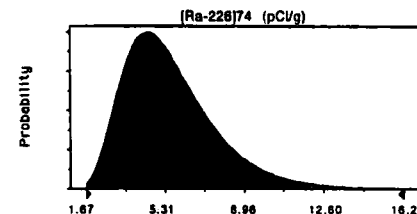
**Assumption: [Ra-226]74 (pCi/g)****Cell: F70**

Lognormal distribution with parameters:

Mean	5.6
Std. deviation	2.2

Selected range is from 0 to ∞

Mean value in simulation was 5.6



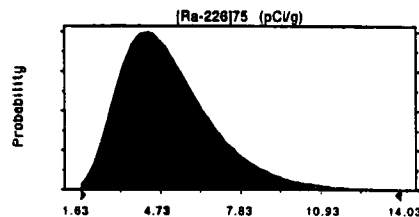
Assumption: [Ra-226]75 (pCi/g)

Cell: F71

Lognormal distribution with parameters:

Mean	5.1
Std. deviation	1.89

Selected range is from 0 to ∞
Mean value in simulation was 5.1

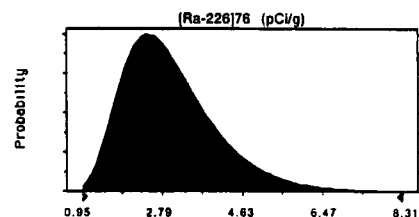
**Assumption: [Ra-226]76 (pCi/g)**

Cell: F72

Lognormal distribution with parameters:

Mean	3.0
Std. deviation	1.12

Selected range is from 0 to ∞
Mean value in simulation was 3.0

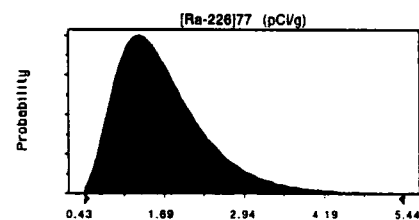
**Assumption: [Ra-226]77 (pCi/g)**

Cell: F73

Lognormal distribution with parameters:

Mean	1.68
Std. deviation	0.74

Selected range is from 0 to ∞
Mean value in simulation was 1.66

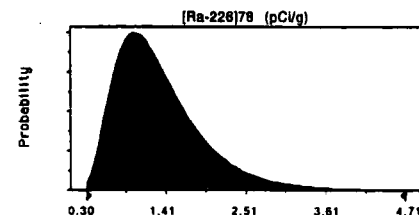
**Assumption: [Ra-226]78 (pCi/g)**

Cell: F74

Lognormal distribution with parameters:

Mean	1.33
Std. deviation	0.64

Selected range is from 0 to ∞
Mean value in simulation was 1.32



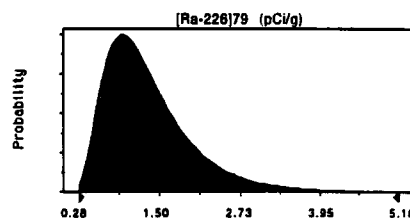
Assumption: [Ra-226]79 (pCi/g)**Cell: F75**

Lognormal distribution with parameters:

Mean	1.35
Std. deviation	0.70

Selected range is from 0 to ∞

Mean value in simulation was 1.37

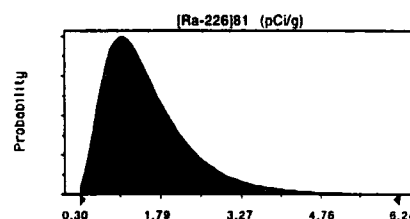
**Assumption: [Ra-226]81 (pCi/g)****Cell: F76**

Lognormal distribution with parameters:

Mean	1.56
Std. deviation	0.84

Selected range is from 0 to ∞

Mean value in simulation was 1.57

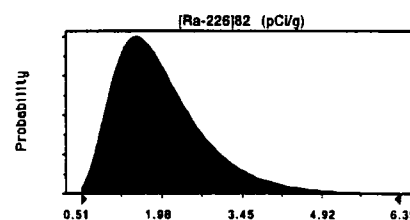
**Assumption: [Ra-226]82 (pCi/g)****Cell: F77**

Lognormal distribution with parameters:

Mean	1.98
Std. deviation	0.87

Selected range is from 0 to ∞

Mean value in simulation was 2.0

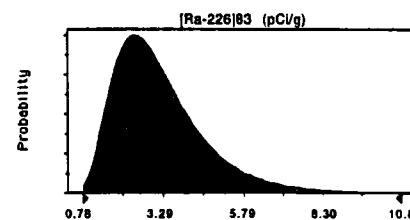
**Assumption: [Ra-226]83 (pCi/g)****Cell: F78**

Lognormal distribution with parameters:

Mean	3.2
Std. deviation	1.47

Selected range is from 0 to ∞

Mean value in simulation was 3.2



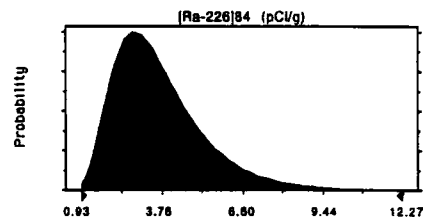
Assumption: [Ra-226]84 (pCi/g)

Cell: F79

Lognormal distribution with parameters:

Mean	3.7
Std. deviation	1.67

Selected range is from 0 to ∞
Mean value in simulation was 3.7

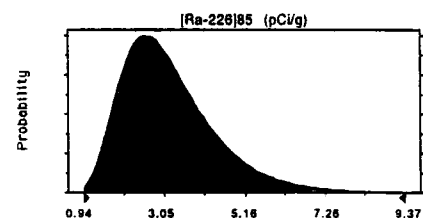
**Assumption: [Ra-226]85 (pCi/g)**

Cell: F80

Lognormal distribution with parameters:

Mean	3.2
Std. deviation	1.27

Selected range is from 0 to ∞
Mean value in simulation was 3.2

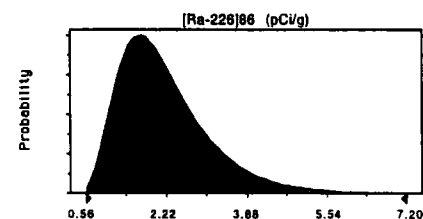
**Assumption: [Ra-226]86 (pCi/g)**

Cell: F81

Lognormal distribution with parameters:

Mean	2.2
Std. deviation	0.98

Selected range is from 0 to ∞
Mean value in simulation was 2.2

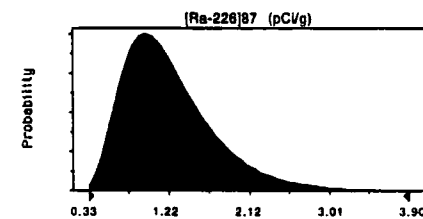
**Assumption: [Ra-226]87 (pCi/g)**

Cell: F82

Lognormal distribution with parameters:

Mean	1.24
Std. deviation	0.53

Selected range is from 0 to ∞
Mean value in simulation was 1.23



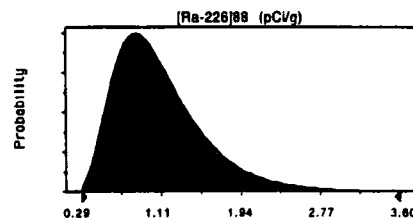
Assumption: [Ra-226]88 (pCi/g)**Cell: F83**

Lognormal distribution with parameters:

Mean	1.11
Std. deviation	0.49

Selected range is from 0 to ∞

Mean value in simulation was 1.11

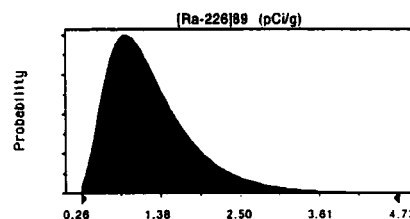
**Assumption: [Ra-226]89 (pCi/g)****Cell: F84**

Lognormal distribution with parameters:

Mean	1.25
Std. deviation	0.64

Selected range is from 0 to ∞

Mean value in simulation was 1.26

**End of Assumptions**

	A	B	C	D	E	F	G	H	I	J	K
1	Future Residential Cancer Risk Model										
2	Montana Company/Montgomery Watson										
3	Common Dose & Toxicity Factors	Grid	Pr.g	Cumulative Pr.g	[Ra-226]g	TSGFg	Effective [Ra-226]g	Incremental [Ra-226]g	ILCRfres.g	Weighted ILCRfres.g	
4	UFdre	1.00	1	0.0134	0.01337	1.45	0.90	1.30	-0.40	0.0E+00	0.0E+00
5	SFfres	0.00000674	2	0					0		
6	EFres	350.00	3	0.00067	0.01404	1.22	0.91	1.11	-0.59	0.0E+00	0.0E+00
7	EDres	30.0	4	0.00134	0.01538	1.35	0.90	1.22	-0.48	0.0E+00	0.0E+00
8	Fo	1.000	5	0.33	0.34972	1.42	0.90	1.28	-0.42	0.0E+00	0.0E+00
9	FI	1.00	6	0.34	0.69074	1.42	0.90	1.28	-0.42	0.0E+00	0.0E+00
10	UCF2	365.25	7	0					0		
11	Common Dose & Toxicity Factors	1.9E-04	8	0.0134	0.70411	1.48	0.90	1.33	-0.37	0.0E+00	0.0E+00
12	mTSGF	0.0500	9	0.0104	0.71448	1.55	0.89	1.38	-0.32	0.0E+00	0.0E+00
13	bTSGF	0.870	11	0.0134	0.72785	1.34	0.90	1.21	-0.49	0.0E+00	0.0E+00
14	(Ra-226)b	1.70	12	0					0		
15			13	0.00033	0.72818	1.58	0.89	1.41	-0.29	0.0E+00	0.0E+00
16	ILCRfres.a	0.0E+00	14	0.00067	0.72885	1.92	0.87	1.68	-0.02	0.0E+00	0.0E+00
17	ILCRfres.b	0.0E+00	15	0					0		
18	ILCRfres.c	0.0E+00	16	0.0037	0.73253	1.53	0.89	1.37	-0.33	0.0E+00	0.0E+00
19	ILCRfres.d	0.0E+00	17	0.00033	0.73287	1.33	0.90	1.20	-0.50	0.0E+00	0.0E+00
20	ILCRfres.e	0.0E+00	18	0.0134	0.74624	1.35	0.90	1.23	-0.47	0.0E+00	0.0E+00
21	ILCRfres.f	0.0E+00	19	0.0104	0.75660	1.45	0.90	1.30	-0.40	0.0E+00	0.0E+00
22	ILCRfres.g	0.0E+00	21	0.0134	0.76998	1.34	0.90	1.21	-0.49	0.0E+00	0.0E+00
23	ILCRfres.h	0.0E+00	22	0.00067	0.77065	1.64	0.89	1.46	-0.24	0.0E+00	0.0E+00
24	ILCRfres.i	0.0E+00	23	0.00033	0.77098	2.40	0.85	2.04	0.34	6.6E-05	2.2E-08
25	ILCRfres.k	3.7E-05	24	0					0		
26	ILCRfres	2.7E-05	25	0.00033	0.77131	3.00	0.82	2.46	0.76	1.5E-04	4.9E-08
27	RANDOM	0.99479	26	0.00100	0.77232	2.10	0.87	1.82	0.12	2.3E-05	2.3E-08
28			27	0.0043	0.77666	1.59	0.89	1.42	-0.28	0.0E+00	0.0E+00
29			28	0.0134	0.79004	1.46	0.90	1.30	-0.40	0.0E+00	0.0E+00
30			29	0.0104	0.80040	1.39	0.90	1.25	-0.45	0.0E+00	0.0E+00
31			31	0.034	0.83450	1.34	0.90	1.21	-0.49	0.0E+00	0.0E+00
32			32	0.00134	0.83584	1.93	0.87	1.69	-0.01	0.0E+00	0.0E+00
33			33	0.00067	0.83651	2.70	0.84	2.25	0.55	1.1E-04	7.2E-08
34			34	0					0		
35			35	0.00067	0.83718	3.30	0.81	2.66	0.96	1.9E-04	1.2E-07
36			36	0.00134	0.83852	2.40	0.85	2.04	0.34	6.6E-05	8.8E-08
37			37	0.0043	0.84286	1.85	0.88	1.62	-0.08	0.0E+00	0.0E+00
38			38	0.0104	0.85323	1.61	0.89	1.43	-0.27	0.0E+00	0.0E+00
39			39	0.0134	0.86660	1.38	0.90	1.24	-0.46	0.0E+00	0.0E+00
40			41	0.034	0.90104	1.62	0.89	1.44	-0.26	0.0E+00	0.0E+00
41			42	0.00134	0.90237	2.20	0.86	1.89	0.19	3.7E-05	5.0E-08
42			43	0.00067	0.90304	3.30	0.81	2.66	0.96	1.9E-04	1.2E-07
43			44	0					0		
44			45	0					0		
45			46	0.00033	0.90338	2.90	0.83	2.39	0.69	1.3E-04	4.5E-08
46			47	0.00033	0.90371	2.20	0.86	1.89	0.19	3.7E-05	1.2E-08
47			48	0.0040	0.90772	1.74	0.88	1.54	-0.16	0.0E+00	0.0E+00
48			49	0.0134	0.92110	1.55	0.89	1.38	-0.32	0.0E+00	0.0E+00
49			51	0.00134	0.92243	1.52	0.89	1.36	-0.34	0.0E+00	0.0E+00
50			52	0.00134	0.92377	2.40	0.85	2.04	0.34	6.6E-05	8.8E-08
51			53	0.00067	0.92444	3.50	0.80	2.78	1.08	2.1E-04	1.4E-07
52			54	0					0		
53			55	0					0		
54			56	0.00033	0.92477	3.00	0.82	2.46	0.76	1.5E-04	4.9E-08
55			57	0.00067	0.92544	2.20	0.86	1.89	0.19	3.7E-05	2.5E-08
56			58	0.0043	0.92979	1.78	0.88	1.57	-0.13	0.0E+00	0.0E+00
57			59	0.0043	0.93414	1.58	0.89	1.41	-0.29	0.0E+00	0.0E+00
58			61	0.00134	0.93547	1.78	0.88	1.57	-0.13	0.0E+00	0.0E+00
59			62	0.00134	0.93681	2.80	0.83	2.32	0.62	1.2E-04	1.6E-07
60			63	0.00067	0.93748	4.80	0.73	3.50	1.80	3.5E-04	2.3E-07
61			64	0					0		
62			65	0					0		
63			66	0.00067	0.93815	2.90	0.83	2.39	0.69	1.3E-04	9.0E-08
64			67	0.00134	0.93949	2.00	0.87	1.74	0.04	7.8E-06	1.0E-08
65			68	0.00134	0.94082	1.58	0.89	1.41	-0.29	0.0E+00	0.0E+00
66			69	0.00134	0.94216	1.53	0.89	1.37	-0.33	0.0E+00	0.0E+00
67			71	0.00134	0.94350	1.52	0.89	1.36	-0.34	0.0E+00	0.0E+00
68			72	0.00134	0.94483	2.80	0.83	2.32	0.62	1.2E-04	1.6E-07
69			73	0.00100	0.94584	5.10	0.72	3.65	1.95	3.8E-04	3.8E-07
70			74	0.00067	0.94651	5.60	0.69	3.86	2.16	4.2E-04	2.8E-07
71			75	0.00067	0.94717	6.10	0.72	3.65	1.95	3.8E-04	2.5E-07
72			76	0.00067	0.94784	3.00	0.82	2.46	0.76	1.5E-04	9.8E-08
73			77	0.0134	0.96122	1.68	0.89	1.49	-0.21	0.0E+00	0.0E+00
74			78	0.0134	0.97459	1.33	0.90	1.20	-0.50	0.0E+00	0.0E+00
75			79	0.0134	0.98796	1.35	0.90	1.22	-0.48	0.0E+00	0.0E+00
76			81	0.00134	0.98930	1.58	0.89	1.39	-0.31	0.0E+00	0.0E+00
77			82	0.00134	0.99064	1.98	0.87	1.72	0.02	4.8E-06	6.4E-09
78			83	0.00134	0.99198	3.20	0.81	2.59	0.89	1.7E-04	2.3E-07
79			84	0.00134	0.99331	3.70	0.79	2.90	1.20	2.3E-04	3.1E-07
80			85	0.00134	0.99465	3.20	0.81	2.59	0.89	1.7E-04	2.3E-07
81			86	0.00134	0.99599	2.20	0.86	1.89	0.19	3.7E-05	5.0E-08
82			87	0.00134	0.99733	1.24	0.91	1.13	-0.57	0.0E+00	0.0E+00
83			88	0.00134	0.99866	1.11	0.91	1.02	-0.68	0.0E+00	0.0E+00
84			89	0.00134	1.00000	1.25	0.91	1.13	-0.57	0.0E+00	0.0E+00
85			81	1.00							

A		B
1	Future Residential Cancer Risk Model	
2	Montgomery Company/Montgomery Watson	
3	Common Dose & Toxicity Factors	
4	UF _{res}	1
5	SP _{res}	0.00000674
6	EF _{res}	360
7	ED _{res}	30
8	F _o	1
9	R	1
10	UCF ₂	365.25
11	Common Dose & Toxicity Factor	=B4*B5*B6*B7*B8*B9/B10
12	mTSGF	=0.05
13	bTSGF	0.97
14	Ra-226lb	1.7
15		
16	ILCR _{res,a}	=IF(B27<E4,J4,IF(B27<E6,J6,IF(B27<E7,J7,IF(B27<E8,J8,IF(B27<E9,J9,IF(B27<E11,J11,IF(B27<E12,J12,IF(B27<E13,J13,0))))))))
17	ILCR _{res,b}	=IF(B27<E13,0,IF(B27<E15,J15,IF(B27<E16,J16,IF(B27<E18,J18,IF(B27<E19,J19,IF(B27<E20,J20,IF(B27<E21,J21,0))))))))
18	ILCR _{res,c}	=IF(B27<E21,0,IF(B27<E22,J22,IF(B27<E23,J23,IF(B27<E24,J24,IF(B27<E26,J26,IF(B27<E27,J27,IF(B27<E28,J28,IF(B27<E29,J29,0))))))))
19	ILCR _{res,d}	=IF(B27<E29,0,IF(B27<E30,J30,IF(B27<E31,J31,IF(B27<E32,J32,IF(B27<E33,J33,IF(B27<E35,J35,IF(B27<E36,J36,IF(B27<E37,J37,0))))))))
20	ILCR _{res,e}	=IF(B27<E37,0,IF(B27<E38,J38,IF(B27<E39,J39,IF(B27<E40,J40,IF(B27<E41,J41,IF(B27<E42,J42,IF(B27<E45,J45,IF(B27<E46,J46,0))))))))
21	ILCR _{res,f}	=IF(B27<E46,0,IF(B27<E47,J47,IF(B27<E48,J48,IF(B27<E49,J49,IF(B27<E50,J50,IF(B27<E51,J51,IF(B27<E54,J54,IF(B27<E55,J55,0))))))))
22	ILCR _{res,h}	=IF(B27<E55,0,IF(B27<E56,J56,IF(B27<E57,J57,IF(B27<E58,J58,IF(B27<E59,J59,IF(B27<E60,J60,IF(B27<E63,J63,IF(B27<E64,J64,0))))))))
23	ILCR _{res,i}	=IF(B27<E64,0,IF(B27<E65,J65,IF(B27<E66,J66,IF(B27<E67,J67,IF(B27<E68,J68,IF(B27<E69,J69,IF(B27<E70,J70,IF(B27<E71,J71,0))))))))
24	ILCR _{res,j}	=IF(B27<E71,0,IF(B27<E72,J72,IF(B27<E73,J73,IF(B27<E74,J74,IF(B27<E75,J75,IF(B27<E76,J76,IF(B27<E77,J77,IF(B27<E78,J78,0))))))))
25	ILCR _{res,k}	=IF(B27<E78,0,IF(B27<E79,J79,IF(B27<E80,J80,IF(B27<E81,J81,IF(B27<E82,J82,IF(B27<E83,J83,0))))))))
26	ILCR _{res}	=SUM(B16:B26)
27	RANDOM	=RAND()
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	C	D	E	F	G	H	I	J	K
1	Grid	Pr	Cumulative Pr	[R-226]g	TSGFg	Effective [R-226]g	Incremental [R-226]g	ICRRes.g	Weighted ILCRRes.g
4	1	0.01337345369441	=D4	1.45	=(\$B\$12*F4)+\$B\$13	=F4*G4	=H4-\$B\$14	=IF(\$B\$11*14<0.0,\$B\$11*14)	=J4*D4
5	2	0							
6	3	0.00066867268472	=D6+E5	1.22	=(\$B\$12*F6)+\$B\$13	=F6*G6	=H6-\$B\$14	=IF(\$B\$11*16<0.0,\$B\$11*16)	=J6*D6
7	4	0.00133734536944	=D7+E6	1.35	=(\$B\$12*F7)+\$B\$13	=F7*G7	=H7-\$B\$14	=IF(\$B\$11*17<0.0,\$B\$11*17)	=J7*D7
8	5	0.33433634236041	=D8+E7	1.42	=(\$B\$12*F8)+\$B\$13	=F8*G8	=H8-\$B\$14	=IF(\$B\$11*18<0.0,\$B\$11*18)	=J8*D8
9	6	0.34102306920762	=D9+E8	1.42	=(\$B\$12*F9)+\$B\$13	=F9*G9	=H9-\$B\$14	=IF(\$B\$11*19<0.0,\$B\$11*19)	=J9*D9
10	7	0							
11	8	0.01337345369441	=D11+E10	1.48	=(\$B\$12*F11)+\$B\$13	=F11*G11	=H11-\$B\$14	=IF(\$B\$11*110<0.0,\$B\$11*110)	=J10*D10
12	9	0.01036442661317	=D12+E11	1.55	=(\$B\$12*F12)+\$B\$13	=F12*G12	=H12-\$B\$14	=IF(\$B\$11*111<0.0,\$B\$11*111)	=J11*D11
13	10	0.01337345369441	=D13+E12	1.54	=(\$B\$12*F13)+\$B\$13	=F13*G13	=H13-\$B\$14	=IF(\$B\$11*112<0.0,\$B\$11*112)	=J12*D12
14	11	0							
15	12	0							
16	13	0.00033433634236	=D15+E14	1.54	=(\$B\$12*F15)+\$B\$13	=F15*G15	=H15-\$B\$14	=IF(\$B\$11*113<0.0,\$B\$11*113)	=J13*D13
17	14	0.00066867268472	=D16+E15	1.92	=(\$B\$12*F16)+\$B\$13	=F16*G16	=H16-\$B\$14	=IF(\$B\$11*114<0.0,\$B\$11*114)	=J14*D14
18	15	0							
19	16	0.00367769976596	=D18+E17	1.53	=(\$B\$12*F18)+\$B\$13	=F18*G18	=H18-\$B\$14	=IF(\$B\$11*115<0.0,\$B\$11*115)	=J15*D15
20	17	0.00033433634236	=D19+E18	1.30	=(\$B\$12*F19)+\$B\$13	=F19*G19	=H19-\$B\$14	=IF(\$B\$11*116<0.0,\$B\$11*116)	=J16*D16
21	18	0.01337345369441	=D20+E19	1.36	=(\$B\$12*F20)+\$B\$13	=F20*G20	=H20-\$B\$14	=IF(\$B\$11*117<0.0,\$B\$11*117)	=J17*D17
22	19	0.01036442661317	=D21+E20	1.45	=(\$B\$12*F21)+\$B\$13	=F21*G21	=H21-\$B\$14	=IF(\$B\$11*118<0.0,\$B\$11*118)	=J18*D18
23	20	0.01337345369441	=D22+E21	1.24	=(\$B\$12*F22)+\$B\$13	=F22*G22	=H22-\$B\$14	=IF(\$B\$11*119<0.0,\$B\$11*119)	=J19*D19
24	21	0.00066867268472	=D23+E22	1.64	=(\$B\$12*F23)+\$B\$13	=F23*G23	=H23-\$B\$14	=IF(\$B\$11*120<0.0,\$B\$11*120)	=J20*D20
25	22	0.00033433634236	=D24+E23	2.4	=(\$B\$12*F24)+\$B\$13	=F24*G24	=H24-\$B\$14	=IF(\$B\$11*121<0.0,\$B\$11*121)	=J21*D21
26	23	0							
27	24	0.00033433634236	=D26+E25	3	=(\$B\$12*F26)+\$B\$13	=F26*G26	=H26-\$B\$14	=IF(\$B\$11*122<0.0,\$B\$11*122)	=J22*D22
28	25	0.0010930902708	=D27+E26	2.1	=(\$B\$12*F27)+\$B\$13	=F27*G27	=H27-\$B\$14	=IF(\$B\$11*123<0.0,\$B\$11*123)	=J23*D23
29	26	0.00434637245068	=D28+E27	1.59	=(\$B\$12*F28)+\$B\$13	=F28*G28	=H28-\$B\$14	=IF(\$B\$11*124<0.0,\$B\$11*124)	=J24*D24
30	27	0.01337345369441	=D29+E28	1.48	=(\$B\$12*F29)+\$B\$13	=F29*G29	=H29-\$B\$14	=IF(\$B\$11*125<0.0,\$B\$11*125)	=J25*D25
31	28	0.01036442661317	=D30+E29	1.39	=(\$B\$12*F30)+\$B\$13	=F30*G30	=H30-\$B\$14	=IF(\$B\$11*126<0.0,\$B\$11*126)	=J26*D26
32	29	0.03410230692076	=D31+E30	1.04	=(\$B\$12*F31)+\$B\$13	=F31*G31	=H31-\$B\$14	=IF(\$B\$11*127<0.0,\$B\$11*127)	=J27*D27
33	30	0.00133734536944	=D32+E31	1.93	=(\$B\$12*F32)+\$B\$13	=F32*G32	=H32-\$B\$14	=IF(\$B\$11*128<0.0,\$B\$11*128)	=J28*D28
34	31	0.00066867268472	=D33+E32	2.7	=(\$B\$12*F33)+\$B\$13	=F33*G33	=H33-\$B\$14	=IF(\$B\$11*129<0.0,\$B\$11*129)	=J29*D29
35	32	0							
36	33	0.00066867268472	=D35+E34	3.3	=(\$B\$12*F35)+\$B\$13	=F35*G35	=H35-\$B\$14	=IF(\$B\$11*130<0.0,\$B\$11*130)	=J30*D30
37	34	0.00133734536944	=D36+E35	2.4	=(\$B\$12*F36)+\$B\$13	=F36*G36	=H36-\$B\$14	=IF(\$B\$11*131<0.0,\$B\$11*131)	=J31*D31
38	35	0.00434637245068	=D37+E36	1.85	=(\$B\$12*F37)+\$B\$13	=F37*G37	=H37-\$B\$14	=IF(\$B\$11*132<0.0,\$B\$11*132)	=J32*D32
39	36	0.01036442661317	=D38+E37	1.61	=(\$B\$12*F38)+\$B\$13	=F38*G38	=H38-\$B\$14	=IF(\$B\$11*133<0.0,\$B\$11*133)	=J33*D33
40	37	0.01337345369441	=D39+E38	1.38	=(\$B\$12*F39)+\$B\$13	=F39*G39	=H39-\$B\$14	=IF(\$B\$11*134<0.0,\$B\$11*134)	=J34*D34
41	38	0.03443664326312	=D40+E39	1.88	=(\$B\$12*F40)+\$B\$13	=F40*G40	=H40-\$B\$14	=IF(\$B\$11*135<0.0,\$B\$11*135)	=J35*D35
42	39	0.00133734536944	=D41+E40	2.2	=(\$B\$12*F41)+\$B\$13	=F41*G41	=H41-\$B\$14	=IF(\$B\$11*136<0.0,\$B\$11*136)	=J36*D36
43	40	0.00066867268472	=D42+E41	3.3	=(\$B\$12*F42)+\$B\$13	=F42*G42	=H42-\$B\$14	=IF(\$B\$11*137<0.0,\$B\$11*137)	=J37*D37
44	41	0							
45	42	0.00033433634236	=D45+E44	2.9	=(\$B\$12*F45)+\$B\$13	=F45*G45	=H45-\$B\$14	=IF(\$B\$11*138<0.0,\$B\$11*138)	=J38*D38
46	43	0.00033433634236	=D46+E45	2.2	=(\$B\$12*F46)+\$B\$13	=F46*G46	=H46-\$B\$14	=IF(\$B\$11*139<0.0,\$B\$11*139)	=J39*D39
47	44	0.00401203610832	=D47+E46	1.74	=(\$B\$12*F47)+\$B\$13	=F47*G47	=H47-\$B\$14	=IF(\$B\$11*140<0.0,\$B\$11*140)	=J40*D40
48	45	0.01337345369441	=D48+E47	1.55	=(\$B\$12*F48)+\$B\$13	=F48*G48	=H48-\$B\$14	=IF(\$B\$11*141<0.0,\$B\$11*141)	=J41*D41
49	46	0.01337345369441	=D49+E48	1.52	=(\$B\$12*F49)+\$B\$13	=F49*G49	=H49-\$B\$14	=IF(\$B\$11*142<0.0,\$B\$11*142)	=J42*D42
50	47	0.00133734536944	=D50+E49	2.4	=(\$B\$12*F50)+\$B\$13	=F50*G50	=H50-\$B\$14	=IF(\$B\$11*143<0.0,\$B\$11*143)	=J43*D43
51	48	0.00066867268472	=D51+E50	3.5	=(\$B\$12*F51)+\$B\$13	=F51*G51	=H51-\$B\$14	=IF(\$B\$11*144<0.0,\$B\$11*144)	=J44*D44
52	49	0							
53	50	0							
54	51	0.00033433634236	=D54+E53	3	=(\$B\$12*F54)+\$B\$13	=F54*G54	=H54-\$B\$14	=IF(\$B\$11*145<0.0,\$B\$11*145)	=J45*D45
55	52	0.00066867268472	=D55+E54	2.2	=(\$B\$12*F55)+\$B\$13	=F55*G55	=H55-\$B\$14	=IF(\$B\$11*146<0.0,\$B\$11*146)	=J46*D46
56	53	0.00434637245068	=D56+E55	1.78	=(\$B\$12*F56)+\$B\$13	=F56*G56	=H56-\$B\$14	=IF(\$B\$11*147<0.0,\$B\$11*147)	=J47*D47
57	54	0.00434637245068	=D57+E56	1.58	=(\$B\$12*F57)+\$B\$13	=F57*G57	=H57-\$B\$14	=IF(\$B\$11*148<0.0,\$B\$11*148)	=J48*D48
58	55	0.00133734536944	=D58+E57	1.78	=(\$B\$12*F58)+\$B\$13	=F58*G58	=H58-\$B\$14	=IF(\$B\$11*149<0.0,\$B\$11*149)	=J49*D49
59	56	0.00133734536944	=D59+E58	2.8	=(\$B\$12*F59)+\$B\$13	=F59*G59	=H59-\$B\$14	=IF(\$B\$11*150<0.0,\$B\$11*150)	=J50*D50
60	57	0.00066867268472	=D60+E59	4.6	=(\$B\$12*F60)+\$B\$13	=F60*G60	=H60-\$B\$14	=IF(\$B\$11*151<0.0,\$B\$11*151)	=J51*D51
61	58	0							
62	59	0							
63	60	0.00066867268472	=D63+E62	2.9	=(\$B\$12*F63)+\$B\$13	=F63*G63	=H63-\$B\$14	=IF(\$B\$11*152<0.0,\$B\$11*152)	=J52*D52
64	61	0.00133734536944	=D64+E63	2	=(\$B\$12*F64)+\$B\$13	=F64*G64	=H64-\$B\$14	=IF(\$B\$11*153<0.0,\$B\$11*153)	=J53*D53
65	62	0.00133734536944	=D65+E64	1.66	=(\$B\$12*F65)+\$B\$13	=F65*G65	=H65-\$B\$14	=IF(\$B\$11*154<0.0,\$B\$11*154)	=J54*D54
66	63	0.00133734536944	=D66+E65	1.83	=(\$B\$12*F66)+\$B\$13	=F66*G66	=H66-\$B\$14	=IF(\$B\$11*155<0.0,\$B\$11*155)	=J55*D55
67	64	0.00133734536944	=D67+E66	1.52	=(\$B\$12*F67)+\$B\$13	=F67*G67	=H67-\$B\$14	=IF(\$B\$11*156<0.0,\$B\$11*156)	=J56*D56
68	65	0.00133734536944	=D68+E67	2.8	=(\$B\$12*F68)+\$B\$13	=F68*G68	=H68-\$B\$14	=IF(\$B\$11*157<0.0,\$B\$11*157)	=J57*D57
69	66	0.0010930902708	=D69+E68	5.1	=(\$B\$12*F69)+\$B\$13	=F69*G69	=H69-\$B\$14	=IF(\$B\$11*158<0.0,\$B\$11*158)	=J58*D58
70	67	0.00066867268472	=D70+E69	5.6	=(\$B\$12*F70)+\$B\$13	=F70*G70	=H70-\$B\$14	=IF(\$B\$11*159<0.0,\$B\$11*159)	=J59*D59
71	68	0.00066867268472	=D71+E70	9.1	=(\$B\$12*F71)+\$B\$13	=F71*G71	=H71-\$B\$14	=IF(\$B\$11*160<0.0,\$B\$11*160)	=J60*D60
72	69	0.00066867268472	=D72+E71	3	=(\$B\$12*F72)+\$B\$13	=F72*G72	=H72-\$B\$14	=IF(\$B\$11*161<0.0,\$B\$11*161)	=J61*D61
73	70	0.01337345369441	=D73+E72	1.60	=(\$B\$12*F73)+\$B\$13	=F73*G73	=H73-\$B\$14	=IF(\$B\$11*162<0.0,\$B\$11*162)	=J62*D62
74	71	0.01337345369441	=D74+E73	1.33	=(\$B\$12*F74)+\$B\$13	=F74*G74	=H74-\$B\$14	=IF(\$B\$11*163<0.0,\$B\$11*163)	=J63*D63
75	72	0.01337345369441	=D75+E74	1.35	=(\$B\$12*F75)+\$B\$13	=F75*G75	=H75-\$B\$14	=IF(\$B\$11*164<0.0,\$B\$11*164)	=J64*D64
76	73	0.00133734536944	=D76+E75	1.86	=(\$B\$12*F76)+\$B\$13	=F76*G76	=H76-\$B\$14	=IF(\$B\$11*165<0.0,\$B\$11*165)	=J65*D65
77	74	0.00133734536944	=D77+E76	1.93	=(\$B\$12*F77)+\$B\$13	=F77*G77	=H77-\$B\$14	=IF(\$B\$11*166<0.0,\$B\$11*166)	=J66*D66
78	75	0.00133734536944	=D78+E77	3.2	=(\$B\$12*F78)+\$B\$13	=F78*G78	=H78-\$B\$14	=IF(\$B\$11*167<0.0,\$B\$11*167)	=J67*D67
79	76	0.00133734536944	=D79+E78	3.7	=(\$B\$12*F79)+\$B\$13	=F79*G79	=H79-\$B\$14	=IF(\$B\$11*168<0.0,\$B\$11*168)	=J68*D68
80	77	0.00133734536944	=D80+E79	3.2	=(\$B\$12*F80)+\$B\$13	=F80*G80	=H80-\$B\$14	=IF(\$B\$11*169<0.0,\$B\$11*169)	=J69*D69
81	78	0.00133734536944	=D81+E80	2.2	=(\$B\$12*F81)+\$B\$13	=F81*G81	=H81-\$B\$14	=IF(\$B\$11*170<0.0,\$B\$11*170)	=J70*D70
82	79	0.00133734536944	=D82+E81	1.24	=(\$B\$12*F82)+\$B\$13	=F82*G82	=H82-\$B\$14	=IF(\$B\$11*171<0.0,\$B\$11*171)	=J71*D71
83	80	0.00133734536944	=D83+E82	1.11	=(\$B\$12*F83)+\$B\$13	=F83*G83	=H83-\$B\$14	=IF(\$B\$11*172<0.0,\$B\$11*172)	=J72*D72
84	81	0.00133734536944	=D84+E83	1.25	=(\$B\$12*F84)+\$B\$13	=F84*G84	=H84-\$B\$14	=IF(\$B\$11*173<0.0,\$B\$11*173)	=J73*D73
85	82	0							
86	83	0							
87	84	0							
88	85	0							
89	86	0							
90	87	0							
91	88	0							
92	89	0							
93	90	0							
94	91	0							
95	92	0							
96	93	0							
97	94	0							
98	95	0							
99	96	0							
100	97	0							
101	98	0							
102	99	0							
103	100	0							
104	101	0							
105	102	0							
106	103	0							
107	104	0							
108	105	0							
109	106	0							
110	107	0							
111	108	0							

Appendix R



MONTGOMERY WATSON

Appendix R

Grid-Specific Results for the Future Residential Cancer Risk Model

Future Residential Subscenario for Monsanto's Soda Springs Plant
Location-Specific Contribution Analysis

Grid	Pr.g	Weighted ILCRfres,q,0.50	Grid Contribution
1	0.0134	0	0%
2	0	0	0%
3	0.00067	0	0%
4	0.00134	0	0%
5	0.33	0	0%
6	0.34	0	0%
7	0	0	0%
8	0.0134	0	0%
9	0.0104	0	0%
11	0.0134	0	0%
12	0	0	0%
13	0.00033	0	0%
14	0.00067	0	0%
15	0	0	0%
16	0.0037	0	0%
17	0.00033	0	0%
18	0.0134	0	0%
19	0.0104	0	0%
21	0.0134	0	0%
22	0.00067	0	0%
23	0.00033	4.2E-12	0.38%
24	0	0	0%
25	0.00033	1.39E-11	1.24%
26	0.00100	0	0%
27	0.0043	0	0%
28	0.0134	0	0%
29	0.0104	0	0%
31	0.034	0	0%
32	0.00134	0	0%
33	0.00067	1.58E-11	1.41%
34	0	0	0%
35	0.00067	3.5E-11	3.1%
36	0.00134	8.0E-12	0.71%
37	0.0043	0	0%
38	0.0104	0	0%
39	0.0134	0	0%
41	0.034	0	0%
42	0.00134	1.18E-12	0.104%
43	0.00067	4.1E-11	3.7%
44	0	0	0%
45	0	0	0%
46	0.00033	9.4E-12	0.84%
47	0.00033	4.8E-14	0.0043%
48	0.0040	0	0%
49	0.0134	0	0%
51	0.00134	0	0%
52	0.00134	5.8E-12	0.50%
53	0.00067	3.8E-11	3.5%
54	0	0	0%
55	0	0	0%
56	0.00033	9.9E-12	0.88%
57	0.00067	3.3E-14	0.0029%
58	0.0043	0	0%
59	0.0043	0	0%
61	0.00134	0	0%
62	0.00134	3.1E-11	2.8%
63	0.00067	1.10E-10	9.8%
64	0	0	0%
65	0	0	0%
66	0.00067	2.3E-11	2.1%
67	0.00134	0	0%
68	0.00134	0	0%
69	0.00134	0	0%
71	0.00134	0	0%
72	0.00134	3.2E-11	2.9%
73	0.00100	1.95E-10	17.4%
74	0.00067	1.45E-10	12.9%
75	0.00067	1.25E-10	11.2%
76	0.00067	2.8E-11	2.6%
77	0.0134	0	0%
78	0.0134	0	0%
79	0.0134	0	0%
81	0.00134	0	0%
82	0.00134	0	0%
83	0.00134	8.5E-11	5.8%
84	0.00134	1.05E-10	9.4%
85	0.00134	7.5E-11	6.7%
86	0.00134	1.87E-12	0.167%
87	0.00134	0	0%
88	0.00134	0	0%
89	0.00134	0	0%
Sum	1.00	1.12E-09	100%

Appendix S



MONTGOMERY WATSON

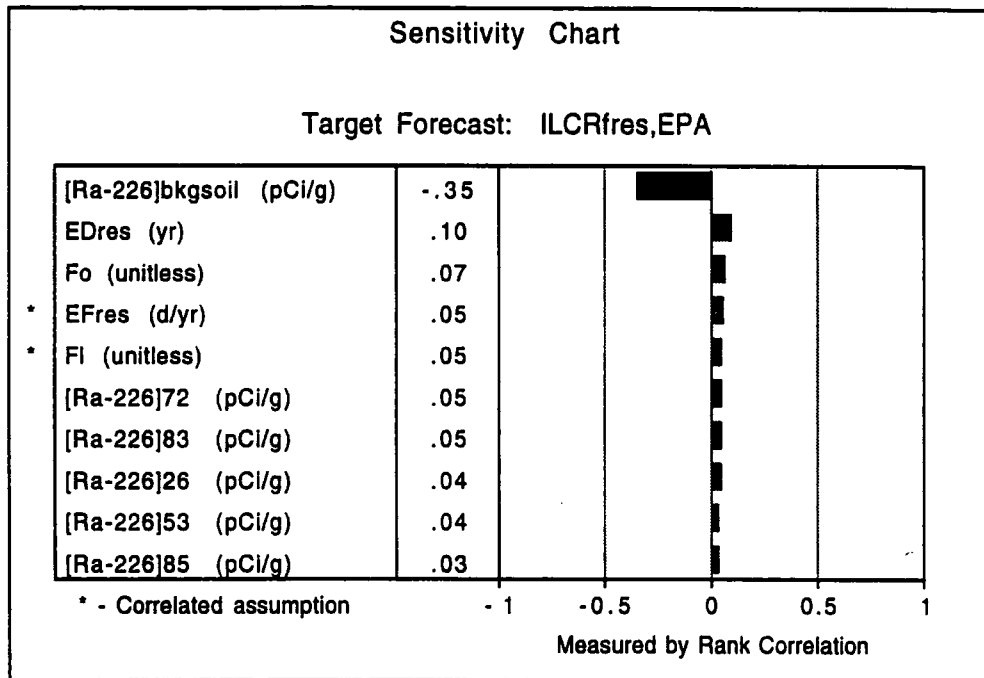
Appendix S

Crystal Ball® Report—EPA's Perspective on the Future Residential Cancer Risk Model

Crystal Ball Report:
EPA's Perspective on the Future Residential Subscenario for Monsanto's
Soda Springs Plant

Simulation started on Tue, Feb 13, 1996 at 13:45:32

Simulation stopped on Tue, Feb 13, 1996 at 14:33:35



Sum of r-squared values = 0.170

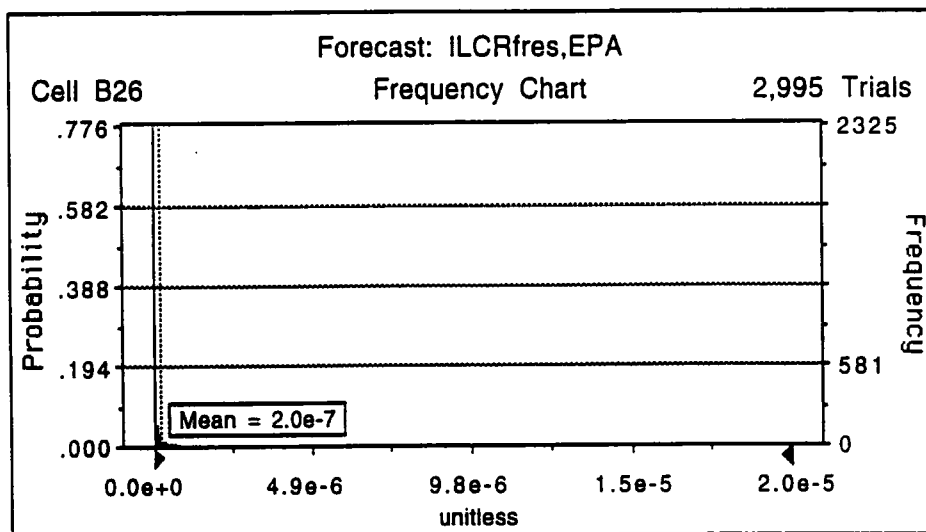
Only the ten "most sensitive" variables are shown above

Forecast: ILCRfres,EPA

Cell: B26

Statistics:

	<u>Value</u>
Trials	2,995
Mean	2.0E-07
Median	0
Standard deviation	9.3E-07
Variance	8.6E-13
Coefficient of variation	4.6



Forecast: ILCRfres,EPA (cont'd)

Cell: B26

Percentiles:

<u>Percentile</u>	<u>ILCRfres,EPA</u>
0.03%	0
5.00%	0
10.00%	0
15.00%	0
20.00%	0
25.00%	0
30.00%	0
35.00%	0
40.00%	0
45.00%	0
50.00%	0
55.00% (Point estimate for southern II area)	0
60.00%	9.5E-10
65.00%	6.7E-09
70.00%	1.81E-08
75.00%	4.6E-08
80.00%	8.7E-08
85.00%	1.64E-07
90.00%	3.8E-07
95.00%	9.6E-07
98.00%	4.9E-06
99.00%	7.2E-06
99.90%	1.75E-05
99.97%	2.0E-05
> 99.97% (Point estimate for northern II area)	1E-04
> 99.97% (Point estimate for northern I and southern I areas)	2E-03

End of Forecast

Assumptions

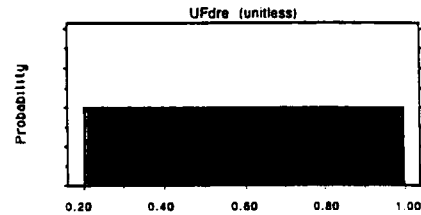
Assumption: UFdre (unitless)

Cell: B4

Uniform distribution with parameters:

Minimum	0.20
Maximum	1.00

Mean value in simulation was 0.60



Assumption: EFres (d/yr)

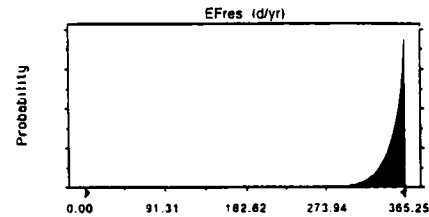
Cell: B6

Beta distribution with parameters:

Alpha	21
Beta	0.92
Scale	365.25

Selected range is from 0 to 365.25

Mean value in simulation was 350



Correlated with:

FI (unitless) (B9)	0.50
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Assumption: EDres (yr)

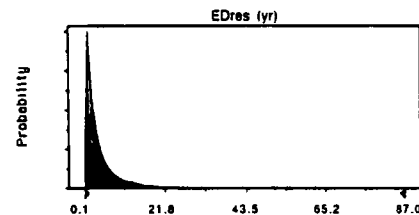
Cell: B7

Lognormal distribution with parameters:

Mean	4.6
Std. deviation	8.7

Selected range is from 0 to ∞

Mean value in simulation was 4.8



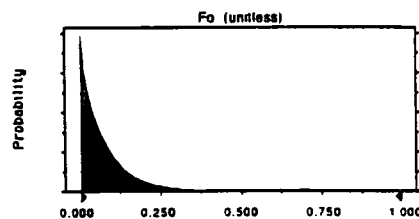
Assumption: Fo (unitless)

Cell: B8

Beta distribution with parameters:

Alpha	0.92
Beta	11.6
Scale	1.00

Selected range is from 0 to 1.00
Mean value in simulation was 0.074



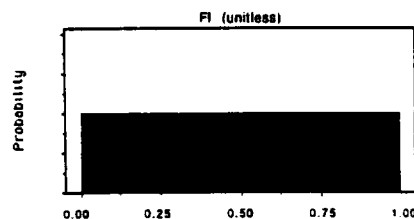
Assumption: FI (unitless)

Cell: B9

Uniform distribution with parameters:

Minimum	0
Maximum	1.00

Mean value in simulation was 0.49



Correlated with:

EFres (d/yr) (B6)

0.50

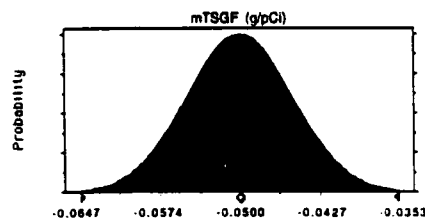
Assumption: mTSGF (g/pCi)

Cell: B12

Normal distribution with parameters:

Mean	-0.050
Std. deviation	0.0049

Selected range is from $-\infty$ to ∞
Mean value in simulation was -0.050



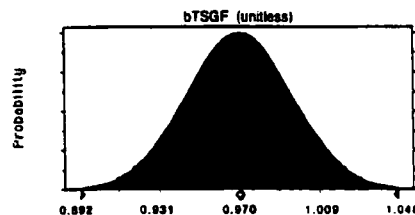
Assumption: bTSGF (unitless)

Cell: B13

Normal distribution with parameters:

Mean	0.97
Std. deviation	0.026

Selected range is from $-\infty$ to ∞
Mean value in simulation was 0.97



Assumption: [Ra-226]bkgsoil (pCi/g)

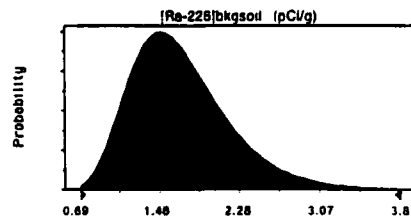
Cell: B14

Lognormal distribution with parameters:

Mean	1.70
Std. deviation	0.50

Selected range is from 0 to ∞

Mean value in simulation was 1.69



Assumption: [Ra-226]1 (pCi/g)

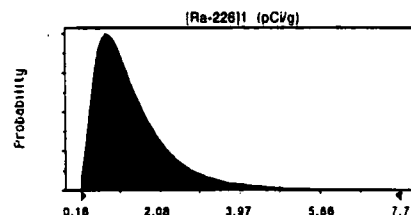
Cell: F4

Lognormal distribution with parameters:

Mean	1.45
Std. deviation	1.00

Selected range is from 0 to ∞

Mean value in simulation was 1.43



Assumption: [Ra-226]3 (pCi/g)

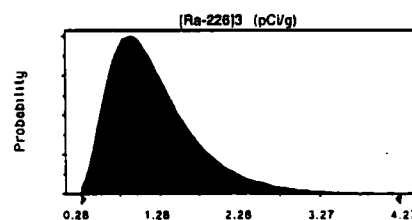
Cell: F6

Lognormal distribution with parameters:

Mean	1.22
Std. deviation	0.58

Selected range is from 0 to ∞

Mean value in simulation was 1.23



Assumption: [Ra-226]4 (pCi/g)

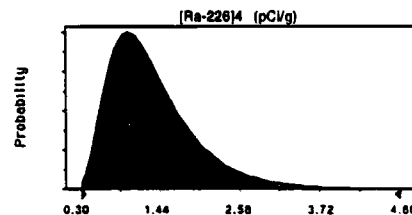
Cell: F7

Lognormal distribution with parameters:

Mean	1.35
Std. deviation	0.66

Selected range is from 0 to ∞

Mean value in simulation was 1.37



Assumption: [Ra-226]5 (pCi/g)

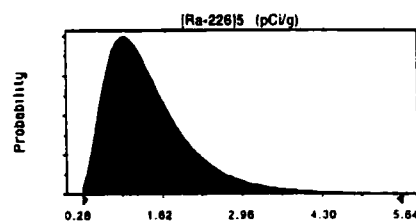
Cell: F8

Lognormal distribution with parameters:

Mean	1.42
Std. deviation	0.76

Selected range is from 0 to ∞

Mean value in simulation was 1.40



Assumption: [Ra-226]6 (pCi/g)

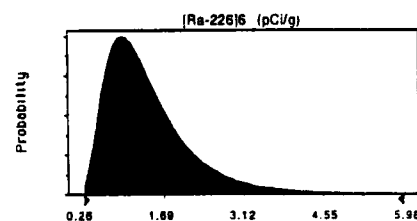
Cell: F9

Lognormal distribution with parameters:

Mean	1.42
Std. deviation	0.80

Selected range is from 0 to ∞

Mean value in simulation was 1.41



Assumption: [Ra-226]8 (pCi/g)

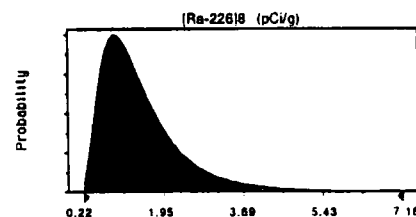
Cell: F11

Lognormal distribution with parameters:

Mean	1.48
Std. deviation	0.94

Selected range is from 0 to ∞

Mean value in simulation was 1.51



Assumption: [Ra-226]9 (pCi/g)

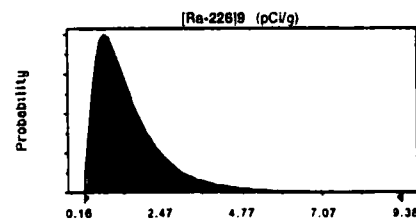
Cell: F12

Lognormal distribution with parameters:

Mean	1.55
Std. deviation	1.18

Selected range is from 0 to ∞

Mean value in simulation was 1.55



Assumption: [Ra-226]11 (pCi/g)

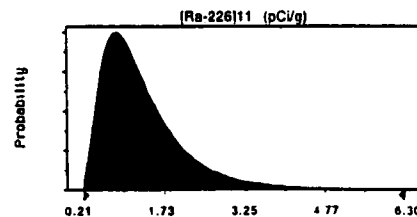
Cell: F13

Lognormal distribution with parameters:

Mean	1.34
Std. deviation	0.83

Selected range is from 0 to ∞

Mean value in simulation was 1.32



Assumption: [Ra-226]13 (pCi/g)

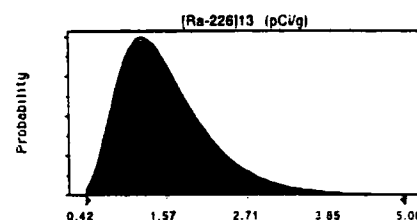
Cell: F15

Lognormal distribution with parameters:

Mean	1.58
Std. deviation	0.68

Selected range is from 0 to ∞

Mean value in simulation was 1.60



Assumption: [Ra-226]14 (pCi/g)

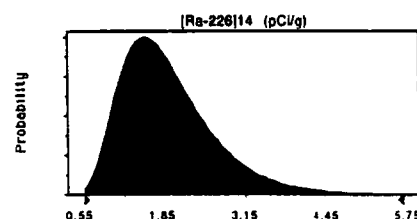
Cell: F16

Lognormal distribution with parameters:

Mean	1.92
Std. deviation	0.78

Selected range is from 0 to ∞

Mean value in simulation was 1.90



Assumption: [Ra-226]16 (pCi/g)

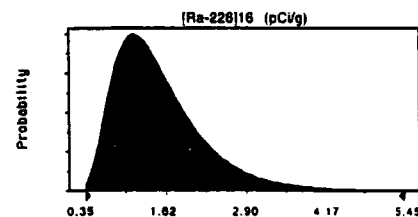
Cell: F18

Lognormal distribution with parameters:

Mean	1.53
Std. deviation	0.74

Selected range is from 0 to ∞

Mean value in simulation was 1.52



Assumption: [Ra-226]17 (pCi/g)

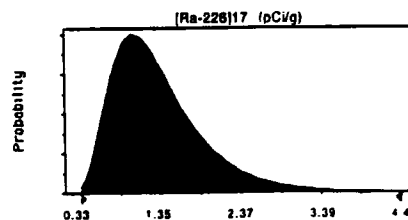
Cell: F19

Lognormal distribution with parameters:

Mean	1.33
Std. deviation	0.60

Selected range is from 0 to ∞

Mean value in simulation was 1.33



Assumption: [Ra-226]18 (pCi/g)

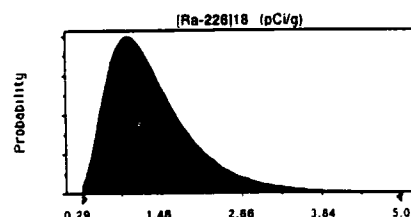
Cell: F20

Lognormal distribution with parameters:

Mean	1.36
Std. deviation	0.68

Selected range is from 0 to ∞

Mean value in simulation was 1.36



Assumption: [Ra-226]19 (pCi/g)

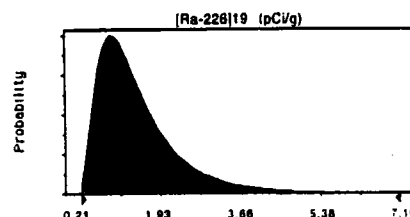
Cell: F21

Lognormal distribution with parameters:

Mean	1.45
Std. deviation	0.93

Selected range is from 0 to ∞

Mean value in simulation was 1.44



Assumption: [Ra-226]21 (pCi/g)

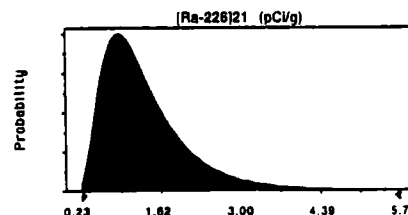
Cell: F22

Lognormal distribution with parameters:

Mean	1.34
Std. deviation	0.77

Selected range is from 0 to ∞

Mean value in simulation was 1.33



Assumption: [Ra-226]22 (pCi/g)

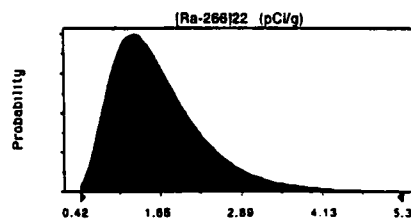
Cell: F23

Lognormal distribution with parameters:

Mean	1.64
Std. deviation	0.73

Selected range is from 0 to ∞

Mean value in simulation was 1.64



Assumption: [Ra-226]23 (pCi/g)

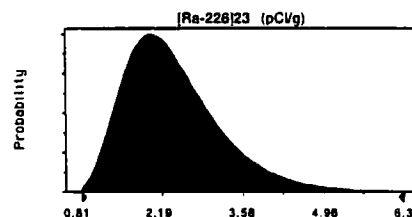
Cell: F24

Lognormal distribution with parameters:

Mean	2.4
Std. deviation	0.85

Selected range is from 0 to ∞

Mean value in simulation was 2.4



Assumption: [Ra-226]25 (pCi/g)

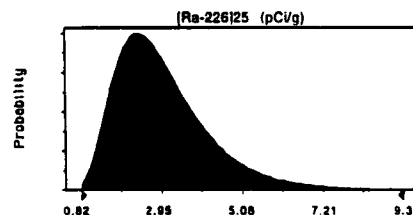
Cell: F26

Lognormal distribution with parameters:

Mean	3.0
Std. deviation	1.27

Selected range is from 0 to ∞

Mean value in simulation was 3.0



Assumption: [Ra-226]26 (pCi/g)

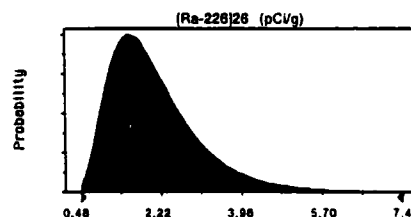
Cell: F27

Lognormal distribution with parameters:

Mean	2.1
Std. deviation	1.01

Selected range is from 0 to ∞

Mean value in simulation was 2.1



Assumption: [Ra-226]27 (pCi/g)

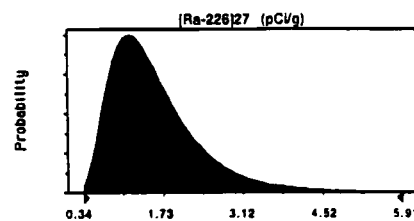
Cell: F28

Lognormal distribution with parameters:

Mean	1.59
Std. deviation	0.80

Selected range is from 0 to ∞

Mean value in simulation was 1.57



Assumption: [Ra-226]28 (pCi/g)

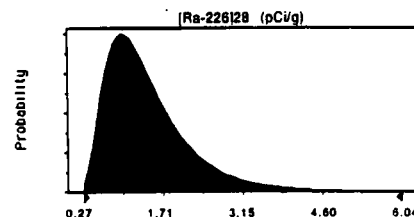
Cell: F29

Lognormal distribution with parameters:

Mean	1.45
Std. deviation	0.81

Selected range is from 0 to ∞

Mean value in simulation was 1.47



Assumption: [Ra-226]29 (pCi/g)

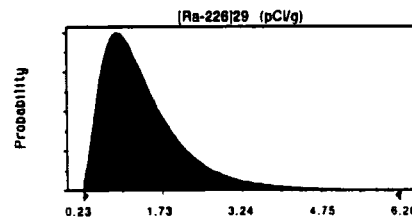
Cell: F30

Lognormal distribution with parameters:

Mean	1.39
Std. deviation	0.83

Selected range is from 0 to ∞

Mean value in simulation was 1.38



Assumption: [Ra-226]31 (pCi/g)

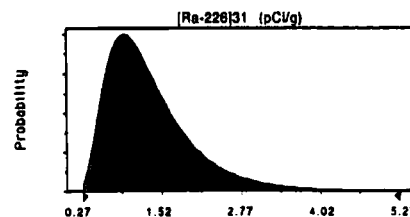
Cell: F31

Lognormal distribution with parameters:

Mean	1.34
Std. deviation	0.71

Selected range is from 0 to ∞

Mean value in simulation was 1.34



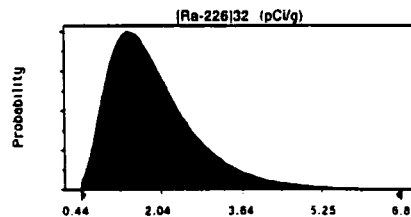
Assumption: [Ra-226]32 (pCi/g)

Cell: F32

Lognormal distribution with parameters:

Mean	1.93
Std. deviation	0.93

Selected range is from 0 to ∞
Mean value in simulation was 1.91



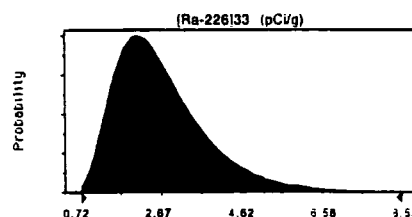
Assumption: [Ra-226]33 (pCi/g)

Cell: F33

Lognormal distribution with parameters:

Mean	2.7
Std. deviation	1.16

Selected range is from 0 to ∞
Mean value in simulation was 2.7



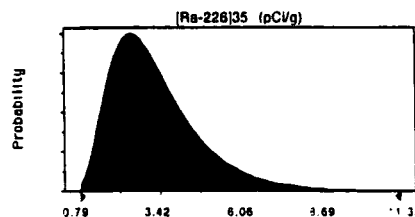
Assumption: [Ra-226]35 (pCi/g)

Cell: F35

Lognormal distribution with parameters:

Mean	3.3
Std. deviation	1.54

Selected range is from 0 to ∞
Mean value in simulation was 3.3



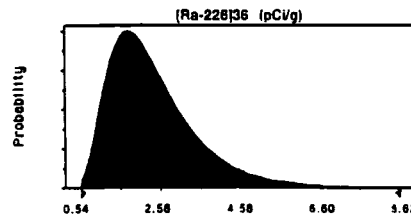
Assumption: [Ra-226]36 (pCi/g)

Cell: F36

Lognormal distribution with parameters:

Mean	2.4
Std. deviation	1.17

Selected range is from 0 to ∞
Mean value in simulation was 2.4



Assumption: [Ra-226]37 (pCi/g)

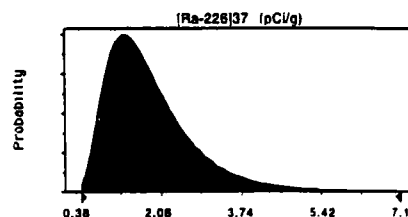
Cell: F37

Lognormal distribution with parameters:

Mean	1.85
Std. deviation	0.96

Selected range is from 0 to ∞

Mean value in simulation was 1.88



Assumption: [Ra-226]38 (pCi/g)

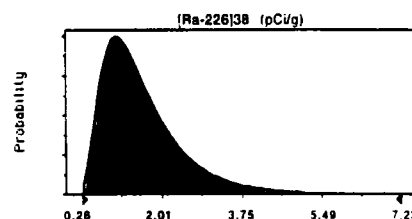
Cell: F38

Lognormal distribution with parameters:

Mean	1.61
Std. deviation	0.96

Selected range is from 0 to ∞

Mean value in simulation was 1.61



Assumption: [Ra-226]39 (pCi/g)

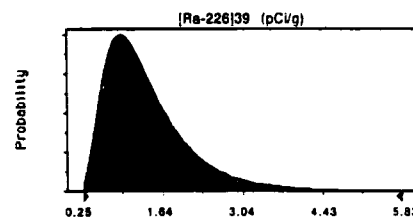
Cell: F39

Lognormal distribution with parameters:

Mean	1.38
Std. deviation	0.78

Selected range is from 0 to ∞

Mean value in simulation was 1.39



Assumption: [Ra-226]41 (pCi/g)

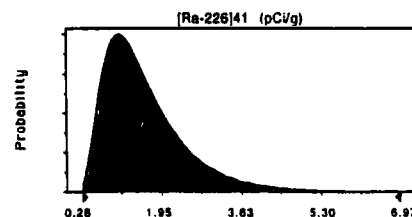
Cell: F40

Lognormal distribution with parameters:

Mean	1.62
Std. deviation	0.93

Selected range is from 0 to ∞

Mean value in simulation was 1.61



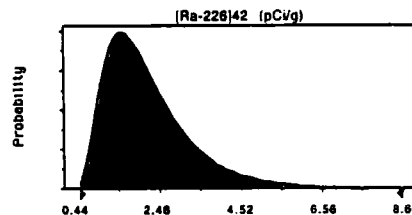
Assumption: [Ra-226]42 (pCi/g)

Cell: F41

Lognormal distribution with parameters:

Mean	2.2
Std. deviation	1.16

Selected range is from 0 to ∞
Mean value in simulation was 2.2



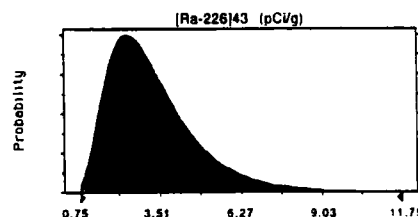
Assumption: [Ra-226]43 (pCi/g)

Cell: F42

Lognormal distribution with parameters:

Mean	3.3
Std. deviation	1.60

Selected range is from 0 to ∞
Mean value in simulation was 3.3



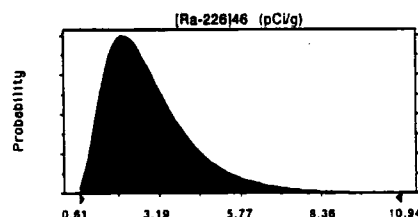
Assumption: [Ra-226]46 (pCi/g)

Cell: F45

Lognormal distribution with parameters:

Mean	2.9
Std. deviation	1.48

Selected range is from 0 to ∞
Mean value in simulation was 2.9



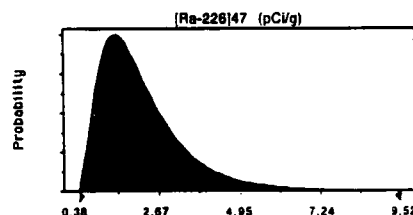
Assumption: [Ra-226]47 (pCi/g)

Cell: F46

Lognormal distribution with parameters:

Mean	2.2
Std. deviation	1.27

Selected range is from 0 to ∞
Mean value in simulation was 2.2



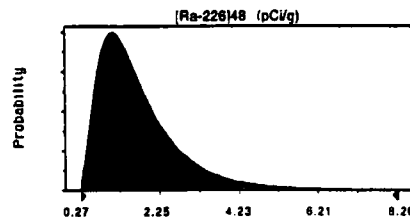
Assumption: [Ra-226]48 (pCi/g)

Cell: F47

Lognormal distribution with parameters:

Mean	1.74
Std. deviation	1.08

Selected range is from 0 to ∞
Mean value in simulation was 1.76



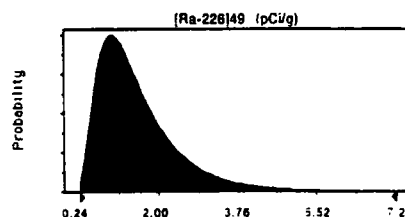
Assumption: [Ra-226]49 (pCi/g)

Cell: F48

Lognormal distribution with parameters:

Mean	1.55
Std. deviation	0.96

Selected range is from 0 to ∞
Mean value in simulation was 1.54



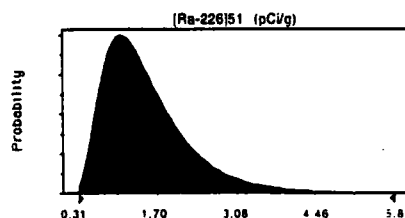
Assumption: [Ra-226]51 (pCi/g)

Cell: F49

Lognormal distribution with parameters:

Mean	1.52
Std. deviation	0.79

Selected range is from 0 to ∞
Mean value in simulation was 1.50



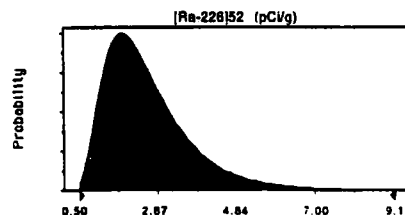
Assumption: [Ra-226]52 (pCi/g)

Cell: F50

Lognormal distribution with parameters:

Mean	2.4
Std. deviation	1.24

Selected range is from 0 to ∞
Mean value in simulation was 2.4



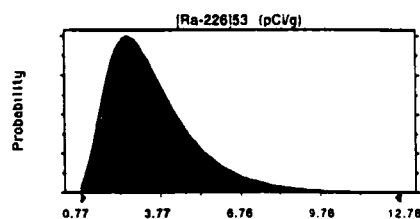
Assumption: [Ra-226]53 (pCi/g)

Cell: F51

Lognormal distribution with parameters:

Mean	3.5
Std. deviation	1.73

Selected range is from 0 to ∞
Mean value in simulation was 3.5



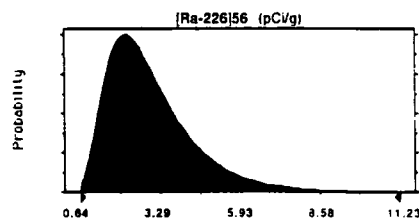
Assumption: [Ra-226]56 (pCi/g)

Cell: F54

Lognormal distribution with parameters:

Mean	3.0
Std. deviation	1.52

Selected range is from 0 to ∞
Mean value in simulation was 3.0



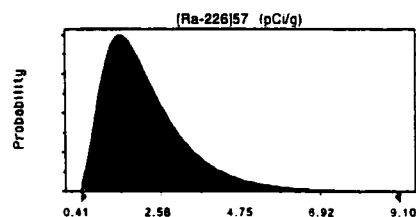
Assumption: [Ra-226]57 (pCi/g)

Cell: F55

Lognormal distribution with parameters:

Mean	2.2
Std. deviation	1.22

Selected range is from 0 to ∞
Mean value in simulation was 2.2



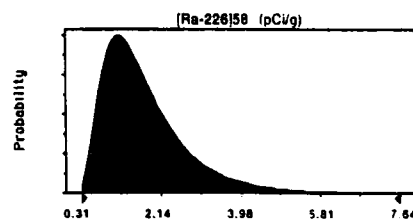
Assumption: [Ra-226]58 (pCi/g)

Cell: F56

Lognormal distribution with parameters:

Mean	1.78
Std. deviation	1.02

Selected range is from 0 to ∞
Mean value in simulation was 1.78



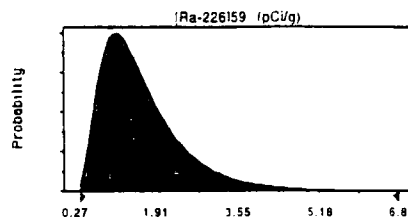
Assumption: [Ra-226]59 (pCi/g)

Cell: F57

Lognormal distribution with parameters:

Mean	1.58
Std. deviation	0.91

Selected range is from 0 to ∞
Mean value in simulation was 1.58



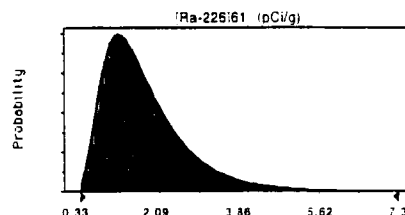
Assumption: [Ra-226]61 (pCi/g)

Cell: F58

Lognormal distribution with parameters:

Mean	1.78
Std. deviation	0.99

Selected range is from 0 to ∞
Mean value in simulation was 1.75



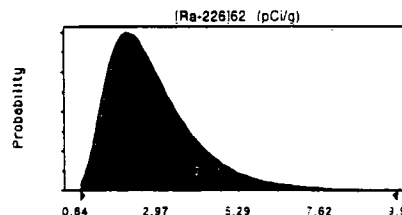
Assumption: [Ra-226]62 (pCi/g)

Cell: F59

Lognormal distribution with parameters:

Mean	2.8
Std. deviation	1.35

Selected range is from 0 to ∞
Mean value in simulation was 2.8



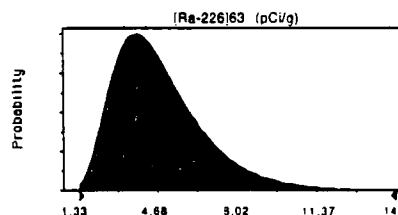
Assumption: [Ra-226]63 (pCi/g)

Cell: F60

Lognormal distribution with parameters:

Mean	4.8
Std. deviation	2.0

Selected range is from 0 to ∞
Mean value in simulation was 4.8



Assumption: [Ra-226]66 (pCi/g)

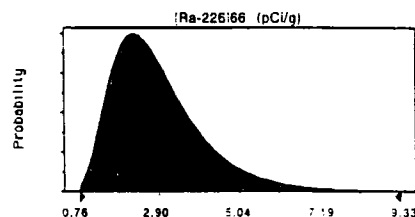
Cell: F63

Lognormal distribution with parameters:

Mean	2.9
Std. deviation	1.27

Selected range is from 0 to ∞

Mean value in simulation was 2.9



Assumption: [Ra-226]67 (pCi/g)

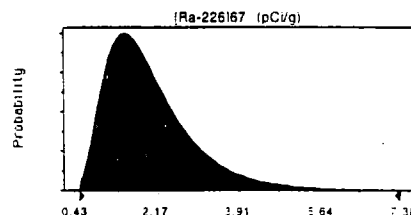
Cell: F64

Lognormal distribution with parameters:

Mean	2.0
Std. deviation	1.00

Selected range is from 0 to ∞

Mean value in simulation was 2.0



Assumption: [Ra-226]68 (pCi/g)

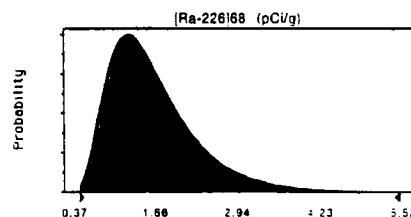
Cell: F65

Lognormal distribution with parameters:

Mean	1.58
Std. deviation	0.75

Selected range is from 0 to ∞

Mean value in simulation was 1.58



Assumption: [Ra-226]69 (pCi/g)

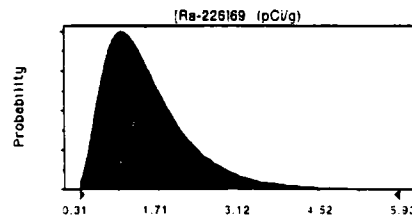
Cell: F66

Lognormal distribution with parameters:

Mean	1.53
Std. deviation	0.80

Selected range is from 0 to ∞

Mean value in simulation was 1.54



Assumption: [Ra-226]71 (pCi/g)

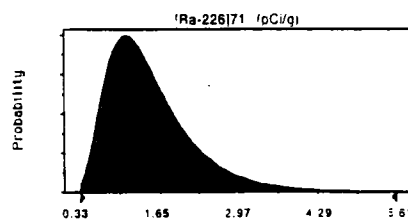
Cell: F67

Lognormal distribution with parameters:

Mean	1.52
Std. deviation	0.76

Selected range is from 0 to ∞

Mean value in simulation was 1.53



Assumption: [Ra-226]72 (pCi/g)

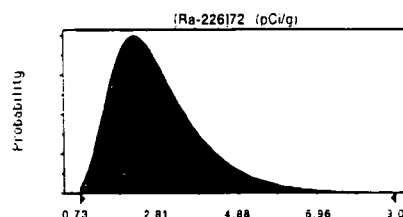
Cell: F68

Lognormal distribution with parameters:

Mean	2.8
Std. deviation	1.23

Selected range is from 0 to ∞

Mean value in simulation was 2.8



Assumption: [Ra-226]73 (pCi/g)

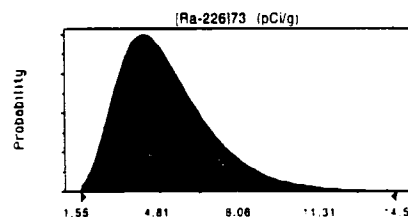
Cell: F69

Lognormal distribution with parameters:

Mean	5.1
Std. deviation	1.97

Selected range is from 0 to ∞

Mean value in simulation was 5.1



Assumption: [Ra-226]74 (pCi/g)

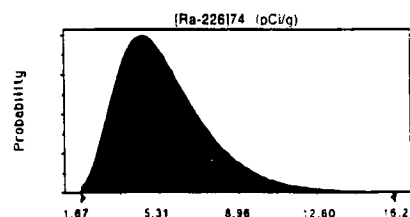
Cell: F70

Lognormal distribution with parameters:

Mean	5.6
Std. deviation	2.2

Selected range is from 0 to ∞

Mean value in simulation was 5.6



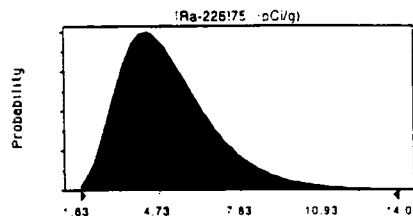
Assumption: [Ra-226]75 (pCi/g)

Cell: F71

Lognormal distribution with parameters:

Mean	5.1
Std. deviation	1.89

Selected range is from 0 to ∞
Mean value in simulation was 5.1



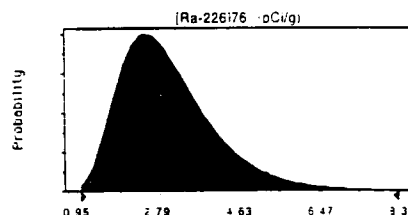
Assumption: [Ra-226]76 (pCi/g)

Cell: F72

Lognormal distribution with parameters:

Mean	3.0
Std. deviation	1.12

Selected range is from 0 to ∞
Mean value in simulation was 3.0



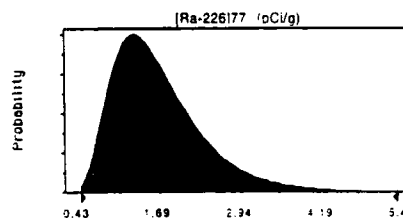
Assumption: [Ra-226]77 (pCi/g)

Cell: F73

Lognormal distribution with parameters:

Mean	1.68
Std. deviation	0.74

Selected range is from 0 to ∞
Mean value in simulation was 1.66



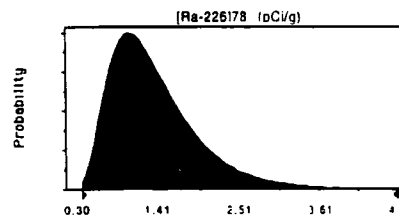
Assumption: [Ra-226]78 (pCi/g)

Cell: F74

Lognormal distribution with parameters:

Mean	1.33
Std. deviation	0.64

Selected range is from 0 to ∞
Mean value in simulation was 1.31



Assumption: [Ra-226]79 (pCi/g)

Cell: F75

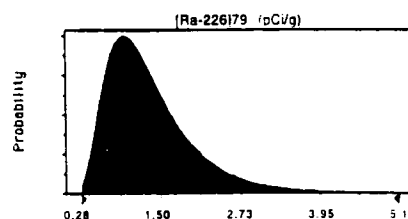
Lognormal distribution with parameters:

Mean 1.35

Std. deviation 0.70

Selected range is from 0 to ∞

Mean value in simulation was 1.34



Assumption: [Ra-226]81 (pCi/g)

Cell: F76

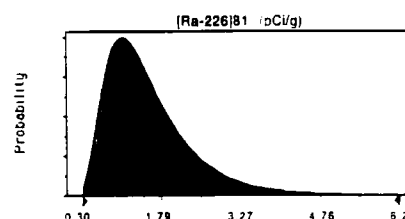
Lognormal distribution with parameters:

Mean 1.56

Std. deviation 0.84

Selected range is from 0 to ∞

Mean value in simulation was 1.57



Assumption: [Ra-226]82 (pCi/g)

Cell: F77

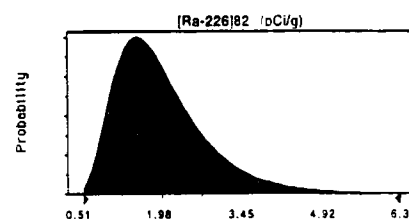
Lognormal distribution with parameters:

Mean 1.98

Std. deviation 0.87

Selected range is from 0 to ∞

Mean value in simulation was 2.0



Assumption: [Ra-226]83 (pCi/g)

Cell: F78

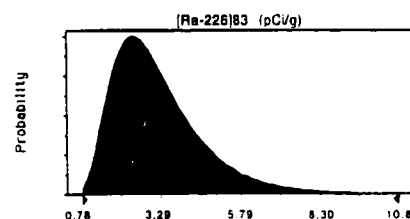
Lognormal distribution with parameters:

Mean 3.2

Std. deviation 1.47

Selected range is from 0 to ∞

Mean value in simulation was 3.2



Assumption: [Ra-226]84 (pCi/g)

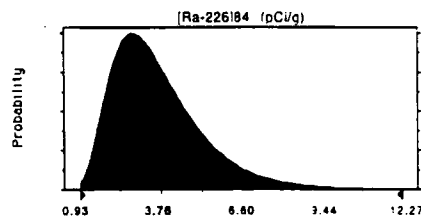
Cell: F79

Lognormal distribution with parameters:

Mean 3.7
Std. deviation 1.67

Selected range is from 0 to ∞

Mean value in simulation was 3.7



Assumption: [Ra-226]85 (pCi/g)

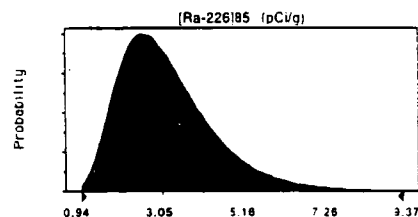
Cell: F80

Lognormal distribution with parameters:

Mean 3.2
Std. deviation 1.27

Selected range is from 0 to ∞

Mean value in simulation was 3.2



Assumption: [Ra-226]86 (pCi/g)

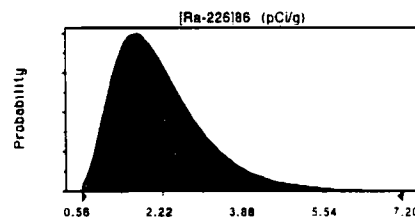
Cell: F81

Lognormal distribution with parameters:

Mean 2.2
Std. deviation 0.98

Selected range is from 0 to ∞

Mean value in simulation was 2.2



Assumption: [Ra-226]87 (pCi/g)

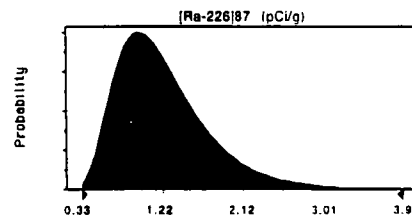
Cell: F82

Lognormal distribution with parameters:

Mean 1.24
Std. deviation 0.53

Selected range is from 0 to ∞

Mean value in simulation was 1.24



Assumption: [Ra-226]88 (pCi/g)

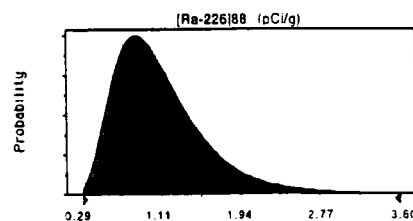
Cell: F83

Lognormal distribution with parameters:

Mean	1.11
Std. deviation	0.49

Selected range is from 0 to ∞

Mean value in simulation was 1.12



Assumption: [Ra-226]89 (pCi/g)

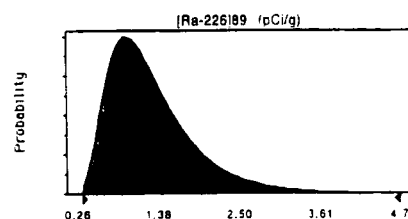
Cell: F84

Lognormal distribution with parameters:

Mean	1.25
Std. deviation	0.64

Selected range is from 0 to ∞

Mean value in simulation was 1.24



End of Assumptions

	A	B	C	D	E	F	G	H	I	J	K
1	Future Residential Cancer Risk Model — Development of Land with Residential Potential at Uniform Spatial Density										
2	Montanto Company/Montgomery Watson										
3	Common Dose & Toxicity Factors	Grid	Prg	Cumulative Pr.g	[Ra-226]g	TSGFg	Effective [Ra-226]g	Incremental [Ra-226]g	ILCRfres.g	Weighted ILCRfres.g	
4	UFdre	1.00	1	0.0183	0.0183	1.45	0.90	1.30	-0.40	0.0E+00	0.0E+00
5	SFres	0.00000674	2	0					0		
6	EFres	350.00	3	0.0091	0.027	1.22	0.91	1.11	-0.59	0.0E+00	0.0E+00
7	EDres	30.0	4	0.0183	0.046	1.35	0.90	1.22	-0.48	0.0E+00	0.0E+00
8	Fo	1.000	5	0.0046	0.050	1.42	0.90	1.28	-0.42	0.0E+00	0.0E+00
9	Fl	1.00	6	0.0137	0.064	1.42	0.90	1.28	-0.42	0.0E+00	0.0E+00
10	UCF2	365.25	7	0					0		
11	Common Dose & Toxicity Factor	1.9E-04	8	0.0183	0.082	1.48	0.90	1.33	-0.37	0.0E+00	0.0E+00
12	mTSGF	0.0500	9	0.0183	0.101	1.55	0.89	1.38	-0.32	0.0E+00	0.0E+00
13	bTSGF	0.970	11	0.0183	0.119	1.64	0.90	1.21	-0.49	0.0E+00	0.0E+00
14	[Ra-226]b	1.70	12	0					0		
15			13	0.0046	0.124	1.58	0.89	1.41	-0.29	0.0E+00	0.0E+00
16	ILCRfres.a	0.0E+00	14	0.0091	0.133	1.92	0.87	1.68	-0.02	0.0E+00	0.0E+00
17	ILCRfres.b	0.0E+00	15	0					0		
18	ILCRfres.c	0.0E+00	16	0.0091	0.142	1.53	0.89	1.37	-0.33	0.0E+00	0.0E+00
19	ILCRfres.d	0.0E+00	17	0.0046	0.146	1.33	0.90	1.20	-0.50	0.0E+00	0.0E+00
20	ILCRfres.e	0.0E+00	18	0.0183	0.165	1.36	0.90	1.23	-0.47	0.0E+00	0.0E+00
21	ILCRfres.f	0.0E+00	19	0.0183	0.183	1.45	0.90	1.30	-0.40	0.0E+00	0.0E+00
22	ILCRfres.h	0.0E+00	21	0.0183	0.201	1.34	0.90	1.21	-0.49	0.0E+00	0.0E+00
23	ILCRfres.i	0.0E+00	22	0.0091	0.210	1.64	0.89	1.46	-0.24	0.0E+00	0.0E+00
24	ILCRfres.j	0.0E+00	23	0.0046	0.215	2.40	0.85	2.04	0.34	6.6E-05	3.0E-07
25	ILCRfres.k	0.0E+00	24	0					0		
26	ILCRfres.EPA	0.0E+00	25	0.0046	0.220	3.00	0.82	2.46	0.76	1.5E-04	6.8E-07
27	RANDOM	0.674	26	0.0137	0.233	2.10	0.87	1.82	0.12	2.3E-05	3.1E-07
28			27	0.0183	0.252	1.59	0.89	1.42	-0.28	0.0E+00	0.0E+00
29			28	0.0183	0.270	1.45	0.90	1.30	-0.40	0.0E+00	0.0E+00
30			29	0.0183	0.288	1.39	0.90	1.25	-0.45	0.0E+00	0.0E+00
31			31	0.0137	0.302	1.34	0.90	1.21	-0.49	0.0E+00	0.0E+00
32			32	0.0183	0.320	1.93	0.87	1.69	-0.01	0.0E+00	0.0E+00
33			33	0.0091	0.329	2.70	0.84	2.25	0.55	1.1E-04	9.8E-07
34			34	0					0		
35			35	0.0091	0.338	3.30	0.81	2.66	0.96	1.9E-04	1.7E-06
36			36	0.0183	0.357	2.40	0.85	2.04	0.34	6.6E-05	1.2E-06
37			37	0.0183	0.375	1.85	0.88	1.62	-0.08	0.0E+00	0.0E+00
38			38	0.0183	0.393	1.61	0.89	1.43	-0.27	0.0E+00	0.0E+00
39			39	0.0183	0.412	1.38	0.90	1.24	-0.46	0.0E+00	0.0E+00
40			41	0.0183	0.430	1.62	0.89	1.44	-0.26	0.0E+00	0.0E+00
41			42	0.0183	0.448	2.20	0.86	1.89	0.19	3.7E-05	6.8E-07
42			43	0.0091	0.457	3.30	0.81	2.66	0.96	1.9E-04	1.7E-06
43			44	0					0		
44			45	0					0		
45			46	0.0046	0.462	2.90	0.83	2.39	0.69	1.3E-04	6.2E-07
46			47	0.0046	0.466	2.20	0.86	1.89	0.19	3.7E-05	1.7E-07
47			48	0.0137	0.480	1.74	0.88	1.54	-0.16	0.0E+00	0.0E+00
48			49	0.0183	0.498	1.55	0.89	1.38	-0.32	0.0E+00	0.0E+00
49			51	0.0183	0.517	1.52	0.89	1.36	-0.34	0.0E+00	0.0E+00
50			52	0.0183	0.535	2.40	0.85	2.04	0.34	6.6E-05	1.2E-06
51			53	0.0091	0.544	3.50	0.80	2.78	1.08	2.1E-04	1.9E-06
52			54	0					0		
53			55	0					0		
54			56	0.0046	0.549	3.00	0.82	2.46	0.76	1.5E-04	6.8E-07
55			57	0.0091	0.558	2.20	0.86	1.89	0.19	3.7E-05	3.4E-07
56			58	0.0183	0.576	1.78	0.88	1.57	-0.13	0.0E+00	0.0E+00
57			59	0.0183	0.594	1.58	0.89	1.41	-0.29	0.0E+00	0.0E+00
58			61	0.0183	0.613	1.78	0.88	1.57	-0.13	0.0E+00	0.0E+00
59			62	0.0183	0.631	2.80	0.83	2.32	0.62	1.2E-04	2.2E-06
60			63	0.0091	0.640	4.60	0.73	3.50	1.80	3.5E-04	3.2E-06
61			64	0					0		
62			65	0					0		
63			66	0.0091	0.649	2.90	0.83	2.39	0.69	1.3E-04	1.2E-06
64			67	0.0183	0.668	2.00	0.87	1.74	0.04	7.8E-06	1.4E-07
65			68	0.0183	0.686	1.58	0.89	1.41	-0.29	0.0E+00	0.0E+00
66			69	0.0183	0.704	1.53	0.89	1.37	-0.33	0.0E+00	0.0E+00
67			71	0.0183	0.722	1.52	0.89	1.36	-0.34	0.0E+00	0.0E+00
68			72	0.0183	0.741	2.80	0.83	2.32	0.62	1.2E-04	2.2E-06
69			73	0.0137	0.754	3.10	0.72	3.65	1.95	3.8E-04	5.2E-06
70			74	0.0091	0.764	3.60	0.69	3.86	2.16	4.2E-04	3.8E-06
71			75	0.0091	0.773	3.10	0.72	3.65	1.95	3.8E-04	3.4E-06
72			76	0.0091	0.782	3.00	0.82	2.46	0.76	1.5E-04	1.3E-06
73			77	0.0183	0.800	1.68	0.89	1.49	-0.21	0.0E+00	0.0E+00
74			78	0.0183	0.818	1.33	0.90	1.20	-0.50	0.0E+00	0.0E+00
75			79	0.0183	0.837	1.25	0.90	1.22	-0.48	0.0E+00	0.0E+00
76			81	0.0183	0.855	1.58	0.89	1.39	-0.31	0.0E+00	0.0E+00
77			82	0.0183	0.873	1.38	0.87	1.72	0.02	4.8E-06	8.7E-08
78			83	0.0183	0.892	3.30	0.81	2.59	0.89	1.7E-04	3.2E-06
79			84	0.0183	0.910	3.70	0.79	2.90	1.20	2.3E-04	4.3E-06
80			85	0.0183	0.928	3.20	0.81	2.59	0.89	1.7E-04	3.2E-06
81			86	0.0183	0.946	3.20	0.86	1.89	0.19	3.7E-05	6.8E-07
82			87	0.0183	0.965	1.24	0.91	1.13	-0.57	0.0E+00	0.0E+00
83			88	0.0183	0.983	1.11	0.91	1.02	-0.68	0.0E+00	0.0E+00
84			89	0.0183	1.001	1.25	0.91	1.13	-0.57	0.0E+00	0.0E+00
85			91	1.00							

A	
1	Future Residential Cancer Risk Model — Development of Land with Residential Potential at Uniform Spatial Density
2	Monsanto Company/Montgomery Watson
3	Common Dose & Toxicity Factors
4	UF _{dre}
5	SF _{ra, res}
6	EF _{res}
7	ED _{res}
8	F _o
9	R
10	UCF ₁₂
11	Common Dose & Toxicity Factor
12	mTSGF
13	bTSGF
14	I(Ra-226)b
15	
16	ILCR _{fres, a}
17	ILCR _{fres, b}
18	ILCR _{fres, c}
19	ILCR _{fres, d}
20	ILCR _{fres, e}
21	ILCR _{fres, f}
22	ILCR _{fres, h}
23	ILCR _{fres, i}
24	ILCR _{fres, j}
25	ILCR _{fres, k}
26	ILCR _{fres, EPA}
27	RANDOM
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B		C
1		
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3		Grid
4	1	1
5	0.00000674	2
6	350	3
7	30	4
8	1	5
9	1	6
10	365.25	7
11	=B4*B5*B6*B7*B8*B9/B10	8
12	-0.05	9
13	0.97	11
14	1.7	12
15		13
16	=IF(B27<E4,J4,IF(B27<E6,J6,IF(B27<E7,J7,IF(B27<E8,J8,IF(B27<E9,J9,IF(B27<E11,J11,IF(B27<E12,J12,IF(B27<E13,J13,0))))))))	14
17	=IF(B27<E13,0,IF(B27<E15,J15,IF(B27<E16,J16,IF(B27<E18,J18,IF(B27<E19,J19,IF(B27<E20,J20,IF(B27<E21,J21,0))))))))	15
18	=IF(B27<E21,0,IF(B27<E22,J22,IF(B27<E23,J23,IF(B27<E24,J24,IF(B27<E26,J26,IF(B27<E27,J27,IF(B27<E28,J28,IF(B27<E29,J29,0))))))))	16
19	=IF(B27<E29,0,IF(B27<E30,J30,IF(B27<E31,J31,IF(B27<E32,J32,IF(B27<E33,J33,IF(B27<E35,J35,IF(B27<E36,J36,IF(B27<E37,J37,0))))))))	17
20	=IF(B27<E37,0,IF(B27<E38,J38,IF(B27<E39,J39,IF(B27<E40,J40,IF(B27<E41,J41,IF(B27<E42,J42,IF(B27<E45,J45,IF(B27<E46,J46,0))))))))	18
21	=IF(B27<E46,0,IF(B27<E47,J47,IF(B27<E48,J48,IF(B27<E49,J49,IF(B27<E50,J50,IF(B27<E51,J51,IF(B27<E54,J54,IF(B27<E55,J55,0))))))))	19
22	=IF(B27<E55,0,IF(B27<E56,J56,IF(B27<E57,J57,IF(B27<E58,J58,IF(B27<E59,J59,IF(B27<E60,J60,IF(B27<E63,J63,IF(B27<E64,J64,0))))))))	21
23	=IF(B27<E64,0,IF(B27<E65,J65,IF(B27<E66,J66,IF(B27<E67,J67,IF(B27<E68,J68,IF(B27<E69,J69,IF(B27<E70,J70,IF(B27<E71,J71,0))))))))	22
24	=IF(B27<E71,0,IF(B27<E72,J72,IF(B27<E73,J73,IF(B27<E74,J74,IF(B27<E75,J75,IF(B27<E76,J76,IF(B27<E77,J77,IF(B27<E78,J78,0))))))))	23
25	=IF(B27<E78,0,IF(B27<E79,J79,IF(B27<E80,J80,IF(B27<E81,J81,IF(B27<E82,J82,IF(B27<E83,J83,J84))))))	24
26	=SUM(B16:B25)	25
27	=RAND()	26
28		27
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75		79
76		81
77		82
78		83
79		84
80		85
81		86
82		87
83		88
84		89
85		=COUNT(C4:C84)

	D	E	F	G	H	I	J
1							
2							
3	Pr.g	Cumulative Pr.g	[Ra-226]g	TSGFg	Effective [Ra-226]g	Incremental [Ra-226]g	ILCRres.g
4	0.0183	=D4	1.45	=(SBS12*F4)+SBS13	=F4*G4	=H4-SBS14	=IF(SBS11*I4<0.0,SBS11*I4)
5	0						=IF(SBS11*I5<0.0,SBS11*I5)*D5
6	0.0091	=D6+E5	1.22	=(SBS12*F6)+SBS13	=F6*G6	=H6-SBS14	=IF(SBS11*I6<0.0,SBS11*I6)
7	0.0183	=D7+E6	1.35	=(SBS12*F7)+SBS13	=F7*G7	=H7-SBS14	=IF(SBS11*I7<0.0,SBS11*I7)
8	0.0046	=D8+E7	1.42	=(SBS12*F8)+SBS13	=F8*G8	=H8-SBS14	=IF(SBS11*I8<0.0,SBS11*I8)
9	0.0137	=D9+E8	1.42	=(SBS12*F9)+SBS13	=F9*G9	=H9-SBS14	=IF(SBS11*I9<0.0,SBS11*I9)
10	0						=IF(SBS11*I10<0.0,SBS11*I10)*D10
11	0.0183	=D11+E10	1.48	=(SBS12*F11)+SBS13	=F11*G11	=H11-SBS14	=IF(SBS11*I11<0.0,SBS11*I11)
12	0.0183	=D12+E11	1.59	=(SBS12*F12)+SBS13	=F12*G12	=H12-SBS14	=IF(SBS11*I12<0.0,SBS11*I12)
13	0.0183	=D13+E12	1.34	=(SBS12*F13)+SBS13	=F13*G13	=H13-SBS14	=IF(SBS11*I13<0.0,SBS11*I13)
14	0						=IF(SBS11*I14<0.0,SBS11*I14)*D14
15	0.0046	=D15+E14	1.55	=(SBS12*F15)+SBS13	=F15*G15	=H15-SBS14	=IF(SBS11*I15<0.0,SBS11*I15)
16	0.0091	=D16+E15	1.92	=(SBS12*F16)+SBS13	=F16*G16	=H16-SBS14	=IF(SBS11*I16<0.0,SBS11*I16)
17	0						=IF(SBS11*I17<0.0,SBS11*I17)*D17
18	0.0091	=D18+E17	1.53	=(SBS12*F18)+SBS13	=F18*G18	=H18-SBS14	=IF(SBS11*I18<0.0,SBS11*I18)
19	0.0046	=D19+E18	1.33	=(SBS12*F19)+SBS13	=F19*G19	=H19-SBS14	=IF(SBS11*I19<0.0,SBS11*I19)
20	0.0183	=D20+E19	1.35	=(SBS12*F20)+SBS13	=F20*G20	=H20-SBS14	=IF(SBS11*I20<0.0,SBS11*I20)
21	0.0183	=D21+E20	1.45	=(SBS12*F21)+SBS13	=F21*G21	=H21-SBS14	=IF(SBS11*I21<0.0,SBS11*I21)
22	0.0183	=D22+E21	1.34	=(SBS12*F22)+SBS13	=F22*G22	=H22-SBS14	=IF(SBS11*I22<0.0,SBS11*I22)
23	0.0091	=D23+E22	1.64	=(SBS12*F23)+SBS13	=F23*G23	=H23-SBS14	=IF(SBS11*I23<0.0,SBS11*I23)
24	0.0046	=D24+E23	2.4	=(SBS12*F24)+SBS13	=F24*G24	=H24-SBS14	=IF(SBS11*I24<0.0,SBS11*I24)
25	0						=IF(SBS11*I25<0.0,SBS11*I25)*D25
26	0.0046	=D26+E25	3	=(SBS12*F26)+SBS13	=F26*G26	=H26-SBS14	=IF(SBS11*I26<0.0,SBS11*I26)
27	0.0137	=D27+E26	2.1	=(SBS12*F27)+SBS13	=F27*G27	=H27-SBS14	=IF(SBS11*I27<0.0,SBS11*I27)
28	0.0183	=D28+E27	1.59	=(SBS12*F28)+SBS13	=F28*G28	=H28-SBS14	=IF(SBS11*I28<0.0,SBS11*I28)
29	0.0183	=D29+E28	1.45	=(SBS12*F29)+SBS13	=F29*G29	=H29-SBS14	=IF(SBS11*I29<0.0,SBS11*I29)
30	0.0183	=D30+E29	1.39	=(SBS12*F30)+SBS13	=F30*G30	=H30-SBS14	=IF(SBS11*I30<0.0,SBS11*I30)
31	0.0137	=D31+E30	1.34	=(SBS12*F31)+SBS13	=F31*G31	=H31-SBS14	=IF(SBS11*I31<0.0,SBS11*I31)
32	0.0183	=D32+E31	1.93	=(SBS12*F32)+SBS13	=F32*G32	=H32-SBS14	=IF(SBS11*I32<0.0,SBS11*I32)
33	0.0091	=D33+E32	2.7	=(SBS12*F33)+SBS13	=F33*G33	=H33-SBS14	=IF(SBS11*I33<0.0,SBS11*I33)
34	0						=IF(SBS11*I34<0.0,SBS11*I34)*D34
35	0.0091	=D35+E34	3.3	=(SBS12*F35)+SBS13	=F35*G35	=H35-SBS14	=IF(SBS11*I35<0.0,SBS11*I35)
36	0.0183	=D36+E35	2.4	=(SBS12*F36)+SBS13	=F36*G36	=H36-SBS14	=IF(SBS11*I36<0.0,SBS11*I36)
37	0.0183	=D37+E36	1.85	=(SBS12*F37)+SBS13	=F37*G37	=H37-SBS14	=IF(SBS11*I37<0.0,SBS11*I37)
38	0.0183	=D38+E37	1.61	=(SBS12*F38)+SBS13	=F38*G38	=H38-SBS14	=IF(SBS11*I38<0.0,SBS11*I38)
39	0.0183	=D39+E38	1.35	=(SBS12*F39)+SBS13	=F39*G39	=H39-SBS14	=IF(SBS11*I39<0.0,SBS11*I39)
40	0.0183	=D40+E39	1.52	=(SBS12*F40)+SBS13	=F40*G40	=H40-SBS14	=IF(SBS11*I40<0.0,SBS11*I40)
41	0.0183	=D41+E40	2.2	=(SBS12*F41)+SBS13	=F41*G41	=H41-SBS14	=IF(SBS11*I41<0.0,SBS11*I41)
42	0.0091	=D42+E41	3.3	=(SBS12*F42)+SBS13	=F42*G42	=H42-SBS14	=IF(SBS11*I42<0.0,SBS11*I42)
43	0						=IF(SBS11*I43<0.0,SBS11*I43)*D43
44	0						=IF(SBS11*I44<0.0,SBS11*I44)*D44
45	0.0046	=D45+E44	2.9	=(SBS12*F45)+SBS13	=F45*G45	=H45-SBS14	=IF(SBS11*I45<0.0,SBS11*I45)
46	0.0046	=D46+E45	2.2	=(SBS12*F46)+SBS13	=F46*G46	=H46-SBS14	=IF(SBS11*I46<0.0,SBS11*I46)
47	0.0137	=D47+E46	1.74	=(SBS12*F47)+SBS13	=F47*G47	=H47-SBS14	=IF(SBS11*I47<0.0,SBS11*I47)
48	0.0183	=D48+E47	1.55	=(SBS12*F48)+SBS13	=F48*G48	=H48-SBS14	=IF(SBS11*I48<0.0,SBS11*I48)
49	0.0183	=D49+E48	1.52	=(SBS12*F49)+SBS13	=F49*G49	=H49-SBS14	=IF(SBS11*I49<0.0,SBS11*I49)
50	0.0183	=D50+E49	2.4	=(SBS12*F50)+SBS13	=F50*G50	=H50-SBS14	=IF(SBS11*I50<0.0,SBS11*I50)
51	0.0091	=D51+E50	3.5	=(SBS12*F51)+SBS13	=F51*G51	=H51-SBS14	=IF(SBS11*I51<0.0,SBS11*I51)
52	0						=IF(SBS11*I52<0.0,SBS11*I52)*D52
53	0						=IF(SBS11*I53<0.0,SBS11*I53)*D53
54	0.0046	=D54+E53	3	=(SBS12*F54)+SBS13	=F54*G54	=H54-SBS14	=IF(SBS11*I54<0.0,SBS11*I54)
55	0.0091	=D55+E54	2.2	=(SBS12*F55)+SBS13	=F55*G55	=H55-SBS14	=IF(SBS11*I55<0.0,SBS11*I55)
56	0.0183	=D56+E55	1.75	=(SBS12*F56)+SBS13	=F56*G56	=H56-SBS14	=IF(SBS11*I56<0.0,SBS11*I56)
57	0.0183	=D57+E56	1.55	=(SBS12*F57)+SBS13	=F57*G57	=H57-SBS14	=IF(SBS11*I57<0.0,SBS11*I57)
58	0.0183	=D58+E57	1.75	=(SBS12*F58)+SBS13	=F58*G58	=H58-SBS14	=IF(SBS11*I58<0.0,SBS11*I58)
59	0.0183	=D59+E58	2.5	=(SBS12*F59)+SBS13	=F59*G59	=H59-SBS14	=IF(SBS11*I59<0.0,SBS11*I59)
60	0.0091	=D60+E59	4.5	=(SBS12*F60)+SBS13	=F60*G60	=H60-SBS14	=IF(SBS11*I60<0.0,SBS11*I60)
61	0						=IF(SBS11*I61<0.0,SBS11*I61)*D61
62	0						=IF(SBS11*I62<0.0,SBS11*I62)*D62
63	0.0091	=D63+E62	2.9	=(SBS12*F63)+SBS13	=F63*G63	=H63-SBS14	=IF(SBS11*I63<0.0,SBS11*I63)
64	0.0183	=D64+E63	2.2	=(SBS12*F64)+SBS13	=F64*G64	=H64-SBS14	=IF(SBS11*I64<0.0,SBS11*I64)
65	0.0183	=D65+E64	1.53	=(SBS12*F65)+SBS13	=F65*G65	=H65-SBS14	=IF(SBS11*I65<0.0,SBS11*I65)
66	0.0183	=D66+E65	1.53	=(SBS12*F66)+SBS13	=F66*G66	=H66-SBS14	=IF(SBS11*I66<0.0,SBS11*I66)
67	0.0183	=D67+E66	1.52	=(SBS12*F67)+SBS13	=F67*G67	=H67-SBS14	=IF(SBS11*I67<0.0,SBS11*I67)
68	0.0183	=D68+E67	2.3	=(SBS12*F68)+SBS13	=F68*G68	=H68-SBS14	=IF(SBS11*I68<0.0,SBS11*I68)
69	0.0137	=D69+E68	5.1	=(SBS12*F69)+SBS13	=F69*G69	=H69-SBS14	=IF(SBS11*I69<0.0,SBS11*I69)
70	0.0091	=D70+E69	5.9	=(SBS12*F70)+SBS13	=F70*G70	=H70-SBS14	=IF(SBS11*I70<0.0,SBS11*I70)
71	0.0091	=D71+E70	5.1	=(SBS12*F71)+SBS13	=F71*G71	=H71-SBS14	=IF(SBS11*I71<0.0,SBS11*I71)
72	0.0091	=D72+E71	3	=(SBS12*F72)+SBS13	=F72*G72	=H72-SBS14	=IF(SBS11*I72<0.0,SBS11*I72)
73	0.0183	=D73+E72	1.55	=(SBS12*F73)+SBS13	=F73*G73	=H73-SBS14	=IF(SBS11*I73<0.0,SBS11*I73)
74	0.0183	=D74+E73	1.39	=(SBS12*F74)+SBS13	=F74*G74	=H74-SBS14	=IF(SBS11*I74<0.0,SBS11*I74)
75	0.0183	=D75+E74	1.35	=(SBS12*F75)+SBS13	=F75*G75	=H75-SBS14	=IF(SBS11*I75<0.0,SBS11*I75)
76	0.0183	=D76+E75	1.55	=(SBS12*F76)+SBS13	=F76*G76	=H76-SBS14	=IF(SBS11*I76<0.0,SBS11*I76)
77	0.0183	=D77+E76	1.98	=(SBS12*F77)+SBS13	=F77*G77	=H77-SBS14	=IF(SBS11*I77<0.0,SBS11*I77)
78	0.0183	=D78+E77	3.2	=(SBS12*F78)+SBS13	=F78*G78	=H78-SBS14	=IF(SBS11*I78<0.0,SBS11*I78)
79	0.0183	=D79+E78	3.7	=(SBS12*F79)+SBS13	=F79*G79	=H79-SBS14	=IF(SBS11*I79<0.0,SBS11*I79)
80	0.0183	=D80+E79	3.2	=(SBS12*F80)+SBS13	=F80*G80	=H80-SBS14	=IF(SBS11*I80<0.0,SBS11*I80)
81	0.0183	=D81+E80	2.2	=(SBS12*F81)+SBS13	=F81*G81	=H81-SBS14	=IF(SBS11*I81<0.0,SBS11*I81)
82	0.0183	=D82+E81	1.24	=(SBS12*F82)+SBS13	=F82*G82	=H82-SBS14	=IF(SBS11*I82<0.0,SBS11*I82)
83	0.0183	=D83+E82	1.11	=(SBS12*F83)+SBS13	=F83*G83	=H83-SBS14	=IF(SBS11*I83<0.0,SBS11*I83)
84	0.0183	=D84+E83	1.25	=(SBS12*F84)+SBS13	=F84*G84	=H84-SBS14	=IF(SBS11*I84<0.0,SBS11*I84)
85	=SUM(D4:D84)						

	K
1	
2	
3	Weighted ILCRfres.g
4	=J4*D4
5	
6	=J6*D6
7	=J7*D7
8	=J8*D8
9	=J9*D9
10	
11	=J11*D11
12	=J12*D12
13	=J13*D13
14	
15	=J15*D15
16	=J16*D16
17	
18	=J18*D18
19	=J19*D19
20	=J20*D20
21	=J21*D21
22	=J22*D22
23	=J23*D23
24	=J24*D24
25	
26	=J26*D26
27	=J27*D27
28	=J28*D28
29	=J29*D29
30	=J30*D30
31	=J31*D31
32	=J32*D32
33	=J33*D33
34	
35	=J35*D35
36	=J36*D36
37	=J37*D37
38	=J38*D38
39	=J39*D39
40	=J40*D40
41	=J41*D41
42	=J42*D42
43	
44	
45	=J45*D45
46	=J46*D46
47	=J47*D47
48	=J48*D48
49	=J49*D49
50	=J50*D50
51	=J51*D51
52	
53	
54	=J54*D54
55	=J55*D55
56	=J56*D56
57	=J57*D57
58	=J58*D58
59	=J59*D59
60	=J60*D60
61	
62	
63	=J63*D63
64	=J64*D64
65	=J65*D65
66	=J66*D66
67	=J67*D67
68	=J68*D68
69	=J69*D69
70	=J70*D70
71	=J71*D71
72	=J72*D72
73	=J73*D73
74	=J74*D74
75	=J75*D75
76	=J76*D76
77	=J77*D77
78	=J78*D78
79	=J79*D79
80	=J80*D80
81	=J81*D81
82	=J82*D82
83	=J83*D83
84	=J84*D84
85	

Appendix T



MONTGOMERY WATSON

Appendix T

Grid-Specific Results for EPA's Perspective on the Future Residential Cancer Risk Model

Future Residential Subscenario for Monsanto's Soda Springs Plant
Location-Specific Contribution Analysis for EPA's Perspective

Grid	Pr.g	Weighted ILCR/res,EPA,q,0.50	Grid Contribution
1	0.0183	0	0%
2	0	0	0%
3	0	0	0%
4	0	0	0%
5	0.0046	0	0%
6	0.0137	0	0%
7	0	0	0%
8	0.0183	0	0%
9	0.0183	0	0%
11	0.0183	0	0%
12	0	0	0%
13	0.0046	0	0%
14	0	0	0%
15	0	0	0%
16	0	0	0%
17	0.0046	0	0%
18	0.0183	0	0%
19	0.0183	0	0%
21	0.0183	0	0%
22	0	0	0%
23	0.0046	6.2E-11	0.39%
24	0	0	0%
25	0.0046	2.0E-10	1.25%
26	0.0137	5.8E-12	0.036%
27	0.0183	0	0%
28	0.0183	0	0%
29	0.0183	0	0%
31	0.0137	0	0%
32	0.0183	0	0%
33	0	1.90E-10	1.19%
34	0	0	0%
35	0	5.7E-10	3.6%
36	0.0183	1.20E-10	0.75%
37	0.0183	0	0%
38	0.0183	0	0%
39	0.0183	0	0%
41	0.0183	0	0%
42	0.0183	2.2E-11	0.138%
43	0	4.9E-10	3.1%
44	0	0	0%
45	0	0	0%
46	0.0046	1.40E-10	0.88%
47	0.0046	9.8E-13	0.0061%
48	0.0137	0	0%
49	0.0183	0	0%
51	0.0183	0	0%
52	0.0183	1.20E-10	0.75%
53	0	5.8E-10	3.6%
54	0	0	0%
55	0	0	0%
56	0.0046	1.50E-10	0.94%
57	0	1.40E-11	0.088%
58	0.0183	0	0%
59	0.0183	0	0%
61	0.0183	0	0%
62	0.0183	4.8E-10	3.0%
63	0	1.50E-09	9.4%
64	0	0	0%
65	0	0	0%
66	0	3.2E-10	2.0%
67	0.0183	0	0%
68	0.0183	0	0%
69	0.0183	0	0%
71	0.0183	0	0%
72	0.0183	5.0E-10	3.1%
73	0.0137	2.7E-09	16.9%
74	0	2.0E-09	12.5%
75	0	1.80E-09	11.3%
76	0	4.2E-10	2.6%
77	0.0183	0	0%
78	0.0183	0	0%
79	0.0183	0	0%
81	0.0183	0	0%
82	0.0183	0	0%
83	0.0183	9.2E-10	5.8%
84	0.0183	1.50E-09	9.4%
85	0.0183	1.10E-09	6.9%
86	0.0183	5.5E-11	0.34%
87	0.0183	0	0%
88	0.0183	0	0%
89	0.0183	0	0%
Sum	1.00	1.60E-08	100%

Appendix U



MONTGOMERY WATSON

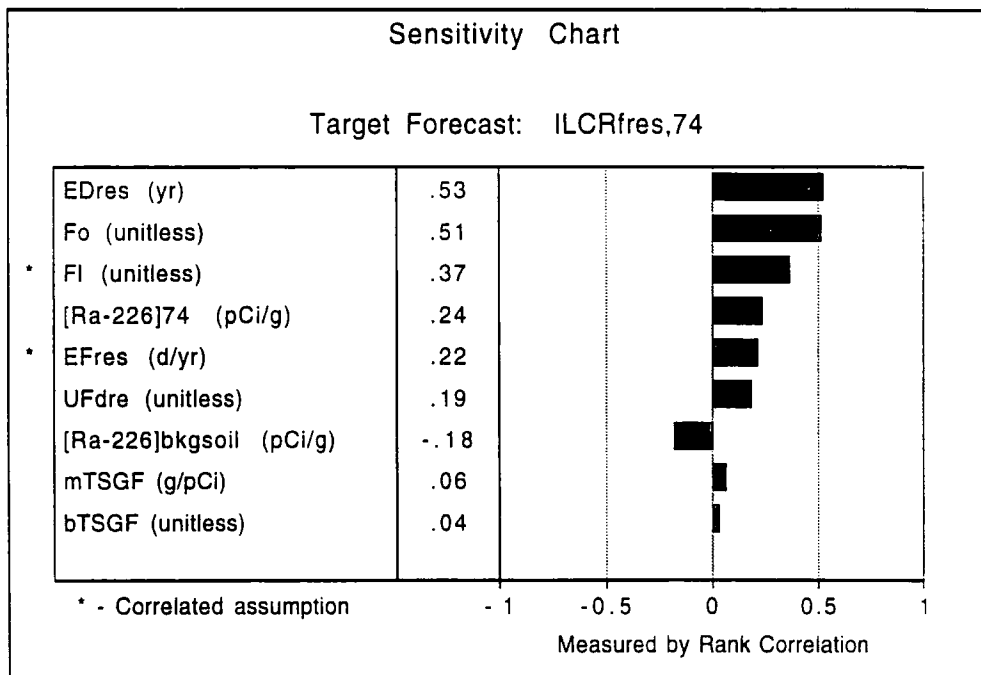
Appendix U

Crystal Ball® Report—Future Residential Cancer Risk Model for the Worst-Case
Subpopulation Along the North Fence Line

Crystal Ball Report:
Future Residential Subscenario for Monsanto's Soda Springs Plant
for a Subpopulation of Residents at the North Fence Line

Simulation started on Tue, Feb 13, 1996 at 12:51:25

Simulation stopped on Tue, Feb 13, 1996 at 12:56:51

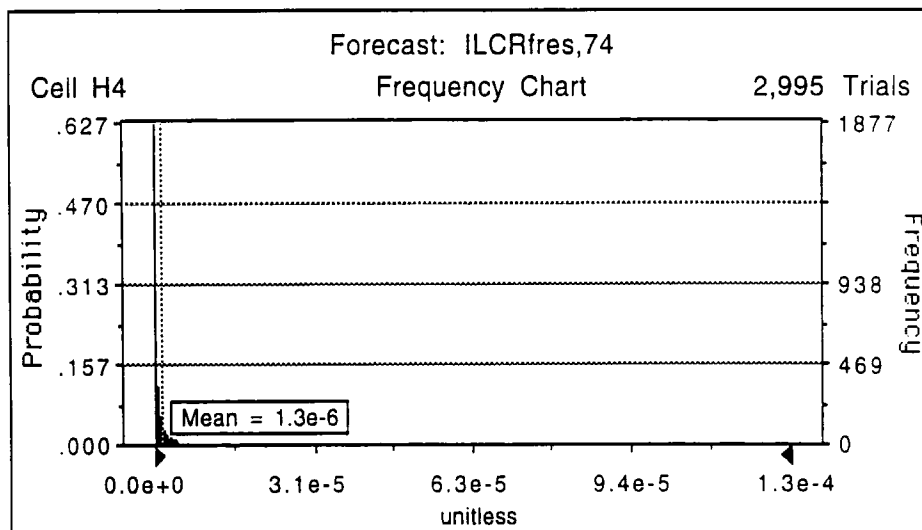


sum of r-squared values = 0.85

Forecast: ILCRfres,74

Cell: H4

Statistics:	<u>Value</u>
Trials	2,995
Mean	1.26E-06
Median	2.2E-07
Standard deviation	4.4E-06
Variance	1.91E-11
Coefficient of variation	3.5



Forecast: ILCRfres,74 (cont'd)

Cell: H4

<u>Percentile</u>	<u>ILCRfres,74</u>
0.03%	0
5.00%	1.62E-09
10.00%	7.3E-09
15.00%	1.57E-08
20.00%	2.7E-08
25.00%	4.2E-08
30.00%	6.3E-08
35.00%	9.0E-08
40.00%	1.26E-07
45.00%	1.67E-07
50.00%	2.2E-07
55.00%	2.7E-07
60.00%	3.6E-07
65.00%	4.8E-07
70.00%	6.6E-07
75.00%	8.8E-07
80.00%	1.27E-06
85.00%	1.86E-06
90.00%	3.0E-06
95.00%	5.5E-06
98.00%	9.9E-06
99.00%	1.51E-05
99.90%	5.9E-05
99.97%	1.26E-04
> 99.97% (Point estimate for northern I area)	2E-03

End of Forecast

Assumptions

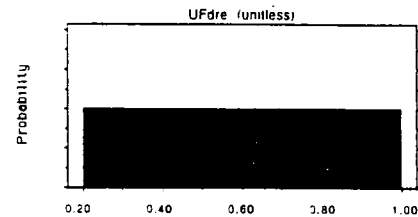
Assumption: UFdre (unitless)

Cell: B4

Uniform distribution with parameters:

Minimum	0.20
Maximum	1.00

Mean value in simulation was 0.60



Assumption: EFres (d/yr)

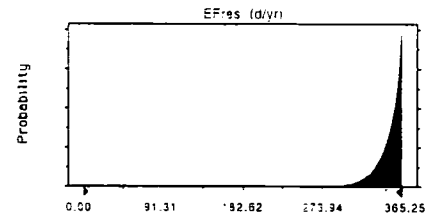
Cell: B6

Beta distribution with parameters:

Alpha	21
Beta	0.92
Scale	365.25

Selected range is from 0 to 365.25

Mean value in simulation was 350



Correlated with:

FI (unitless) (B9)	0.50
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Assumption: EDres (yr)

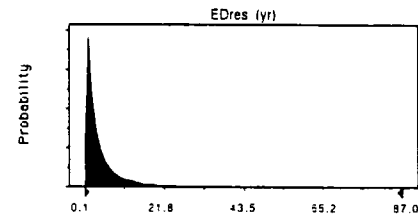
Cell: B7

Lognormal distribution with parameters:

Mean	4.6
Std. deviation	8.7

Selected range is from 0 to ∞

Mean value in simulation was 4.3



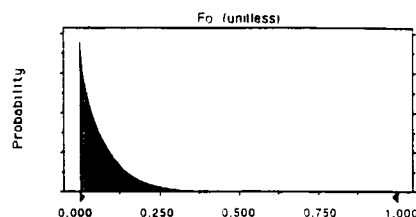
Assumption: Fo (unitless)

Cell: B8

Beta distribution with parameters:

Alpha	0.92
Beta	11.6
Scale	1.00

Selected range is from 0 to 1.00
Mean value in simulation was 0.074



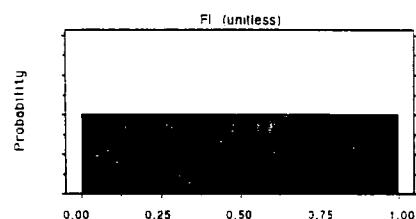
Assumption: FI (unitless)

Cell: B9

Uniform distribution with parameters:

Minimum	0
Maximum	1.00

Mean value in simulation was 0.51



Correlated with:

EFres (d/yr) (B6)

0.50

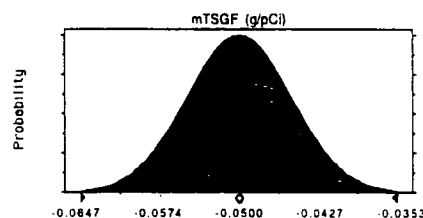
Assumption: mTSGF (g/pCi)

Cell: B12

Normal distribution with parameters:

Mean	-0.050
Std. deviation	0.0049

Selected range is from $-\infty$ to ∞
Mean value in simulation was -0.050



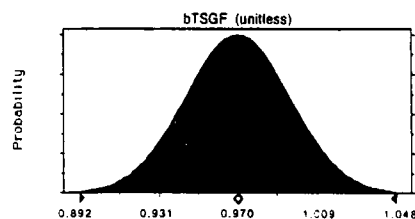
Assumption: bTSGF (unitless)

Cell: B13

Normal distribution with parameters:

Mean	0.97
Std. deviation	0.026

Selected range is from $-\infty$ to ∞
Mean value in simulation was 0.97



Assumption: [Ra-226]bkgsoil (pCi/g)

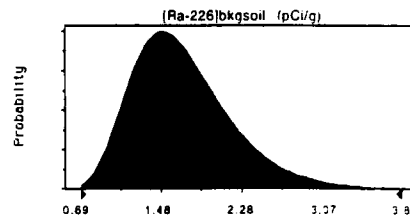
Cell: B14

Lognormal distribution with parameters:

Mean	1.70
Std. deviation	0.50

Selected range is from 0 to ∞

Mean value in simulation was 1.72



Assumption: [Ra-226]74 (pCi/g)

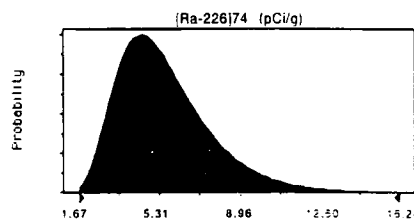
Cell: D4

Lognormal distribution with parameters:

Mean	5.6
Std. deviation	2.2

Selected range is from 0 to ∞

Mean value in simulation was 5.7



End of Assumptions

	A	B	C	D	E	F	G	H
1	Future Residential Cancer Risk Model for the North Fencelline							
2	Monsanto Company/Montgomery Watson							
3	Common Dose & Toxicity Factors		Grid	[Ra-226]g	TSGFg	Effective [Ra-226]g	Incremental [Ra-226]g	ILCRfres,g
4	UFdre	1.00	74	13.0	0.28	3.64	1.94	3.8E-04
5	SFra,res	0.00000674						
6	EFres	350.00						
7	EDres	30.0						
8	Fo	1.000						
9	FI	1.00						
10	UCFt2	365.25						
11	Common Dose & Toxicity Factor	1.9E-04						
12	mTSGF	-0.0500						
13	bTSGF	0.930						
14	[Ra-226]b	1.70						

Montgomery Watson

	A	B	C	D	E	F	G	H
1	Future Residential Cancer Risk Model for the North Fenceline							
2	Monsanto Company/Montgomery Watson							
3	Common Dose & Toxicity Factors		Grid	[Ra-226]g	TSGFg	Effective [Ra-226]g	Incremental [Ra-226]g	ILCRires,g
4	UFdre	1	74	13	=(B12*D4)+B13	=D4*E4	=F4-B14	=IF(B11*G4<0.0,B11*G4)
5	SFra,res	0.00000674						
6	EFres	350						
7	EDres	30						
8	Fo	1						
9	Fi	1						
10	UCFI2	365.25						
11	Common Dose & Toxicity Factor	=B4*B5*B6*B7*B8*B9/B10						
12	mTSGF	-0.05						
13	bTSGF	0.93						
14	[Ra-226]b	1.7						

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